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Opportunities for Increasing Water Yields and Other Multiple Use Values on Ponderosa Pine Forest Lands

Abstract

Multiple use productivity is described for watershed lands in the ponderosa pine type of Arizona, with special emphasis on the Beaver Creek Pilot Watershed near Flagstaff. Yields of timber, herbage, and water under past management are reported, along with information on wildlife values, esthetics, flood and sedimentation hazards, and water quality. Changes in productivity and environmental quality are then described following five experimental land treatments including livestock grazing and various levels of forest thinning and clearing. Preliminary analytical procedures for predicting treatment responses and costs allow the user to estimate the tradeoffs in production and environmental quality. Some further research needed for bringing these and other response models to operational capability is described.

Keywords: Water-yield improvement, forest management, multiple use, *Pinus ponderosa*.

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by

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Introduction

This report documents the background of water yield and multiple use research in the ponderosa pine type in Arizona, and sets forth the objectives of the program initiated on the Beaver Creek Pilot Watershed on the Coconino National Forest near Flagstaff to carry out the research. It characterizes the Beaver Creek area in physical terms, and describes its multiple use production under present management. This section is followed by an updated presentation of results of the various treatments being pilot tested. Models are described that eventually will be incorporated into a multiple use management planning system of broad applicability. Interrelationships of the various products are discussed and implications are pointed out indicating the best general forest density levels to achieve various management objectives. Finally, needed research is described to provide better management tools.

Background

In the mid-1950's, water-user and ranching groups in the Salt-Verde Basin called attention to the possibility of treating watersheds to increase irrigation water yields and provide more grass for grazing. In response to these concerns, the Chief of the Forest Service approved in August 1956 the "Arizona Water Management Project, Beaver Creek." The objectives of the project were to observe the effects of vegetative changes on water yield, soil, forage, fish, wildlife, and recreation, and to determine whether these changes increased the risk from fire, insects, and disease. The work in 1956-57 was to be an action watershed improvement program involving clearing of 4,000 acres of juniper and silvicultural thinning of 1,200 acres of ponderosa pine.

During this period, a staff of watershed management experts studied the economic feasibility of obtaining additional water for irrigation from the watersheds of Arizona. The report resulting from this study, known as the "Barr Report," was released in December 1956 (Barr 1956).

The Arizona Water Resources Committee in February 1957 recommended a program of action and research, the purpose of which was to find out if modification of vegetation could produce more water on the Salt-Verde Watershed. Specific recommendations were made for projects in spruce-fir, ponderosa pine, juniper, chaparral, and streambed vegetation (Brown 1970).

The Beaver Creek watershed was chosen to represent the juniper and pine types. In the period 1957-62, stream gages were built on 18 small watersheds of 66 to 2,036 acres: three in the Utah juniper type, three in the alligator juniper type, and 12 in the ponderosa pine type. Stream gages were also built on two large watersheds, Woods and Bar M, to provide an opportunity for testing composite treatments developed on the small watersheds. Sediment-measuring installations of new design were constructed on nine of the watersheds. Also, a network of precipitation gages was installed. Timber, range, and wildlife were inventoried, the latter by the Arizona Game and Fish Department.

Objectives of the Beaver Creek Watershed Evaluation Program

The general objective of the project as assigned in the 1960's was to evaluate land management measures designed to increase water yields. While water yield was to receive major consideration, changes in forage and timber production, wildlife populations, recreational value, and erosion and sediment movement were also to be evaluated. Costs and benefits of the various treatments were to be studied so that the total project could be evaluated. These objectives, maintained until 1971, resulted in six pilot treatment tests on pine watersheds and three in the juniper.

In 1971 an Interdisciplinary Team assigned by the Chief of the Forest Service reviewed the Project and recommended the objectives be

changed to read as follows:

1. To develop multiple use production data for alternative land management practices, and determine their ecological and environmental impacts.
2. To develop, test, and refine physical product models that will estimate responses to management activities for use in decisionmaking in the Southwest.
3. To develop and test an economic evaluation and planning model.
4. To pilot-test and demonstrate on an operational scale the physical product and evaluation-planning models and other management procedures thus developed.
5. To develop from the physical and economic models a series of management models with broader geographic, economic, and environmental application potential.
6. To publish a report explaining the physical responses to land management treatments, procedures recommended for planning management programs, and how a balanced land management program in the Salt-Verde Basin might affect resource outputs and environmental quality.

This report will document the progress that has been made toward meeting these objectives. In brief, it will show that the objectives of the sixties and the first objective of the seventies have largely been met. The modeling and large-scale pilot testing objectives of the seventies will be discussed, although only limited results can be presented.

Physical Characteristics and Productivity of the Ponderosa Pine Type

Ponderosa pine forests occupy about 4,282,000 acres in Arizona and 4,681,000 acres in New Mexico (Spencer 1966; Choate 1966). In the Salt-Verde Basin in Arizona they occupy more than 1,650,000 acres or 20 percent of the watershed (fig. 1); they produce nearly one-half of the total runoff of the Salt River (Barr 1956). The Beaver Creek watershed, to be characterized in this section, is about one-third ponderosa pine (fig. 2). Total area of Beaver Creek is about 275,000 acres.

Physiography of the Pine Type on Beaver Creek

A high plateau, sloping mesas and breaks, steep canyons, and valleys characterize the topography on Beaver Creek. Elevations in the pine type vary from about 6,800 feet to 8,000 feet. The bedrock underlying the area consists of igneous rocks of volcanic origin; below them are sedimentary rocks of Kaibab, Coconino, and Supai formations.

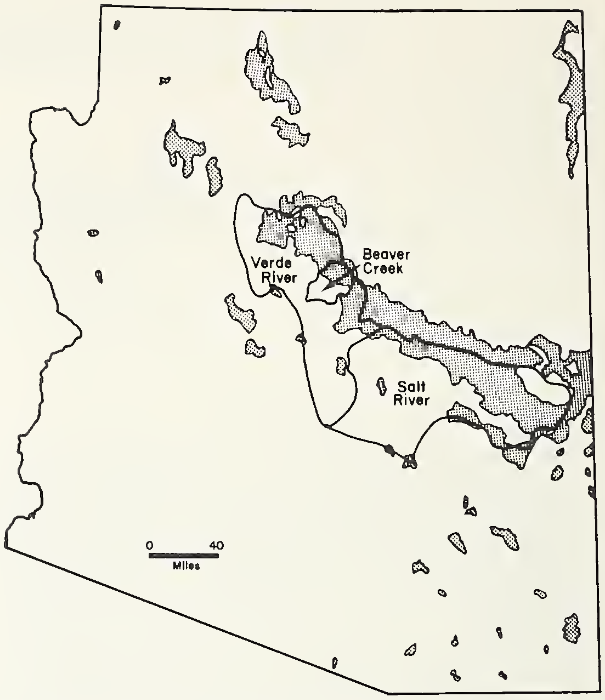

Figure 1.—The ponderosa pine type in Arizona.

Geology of the watershed was studied by Beus, Rush, and Smouse,[2] and Scholtz (1968). Their inventories included, in addition to rock types, identification of geologic features such as faults and fractures that can be quantified and used in water prediction models.

The soils, developed on basalt and cinders, are mostly silty clays and silty clay loams less than 2-1/2 feet deep. They are described in detail by Anderson, Williams and Creeze (1960) and Williams and Anderson (1967). To better predict the hydrologic properties of the soils, the relationships between physical and hydrologic characteristics of soils within the various soil management areas were studied in the laboratory by Rector (1969), Ryan (1969), and Thames.[3]

Hydrologic Characteristics of the Pine Type on Beaver Creek

This section briefly describes the hydrologic characteristics of the southwest ponderosa pine type, and in particular the Beaver Creek

[2]*Unpublished reports available at the Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.*

[3]*Thames, John L. A study to determine the hydrologic and physical properties of some Beaver Creek soils. Final report of a cooperative study between the Univ. of Ariz. and the Rocky Mt. For. and Range Exp. Stn., 331 p. Flagstaff, Ariz. 1969.*

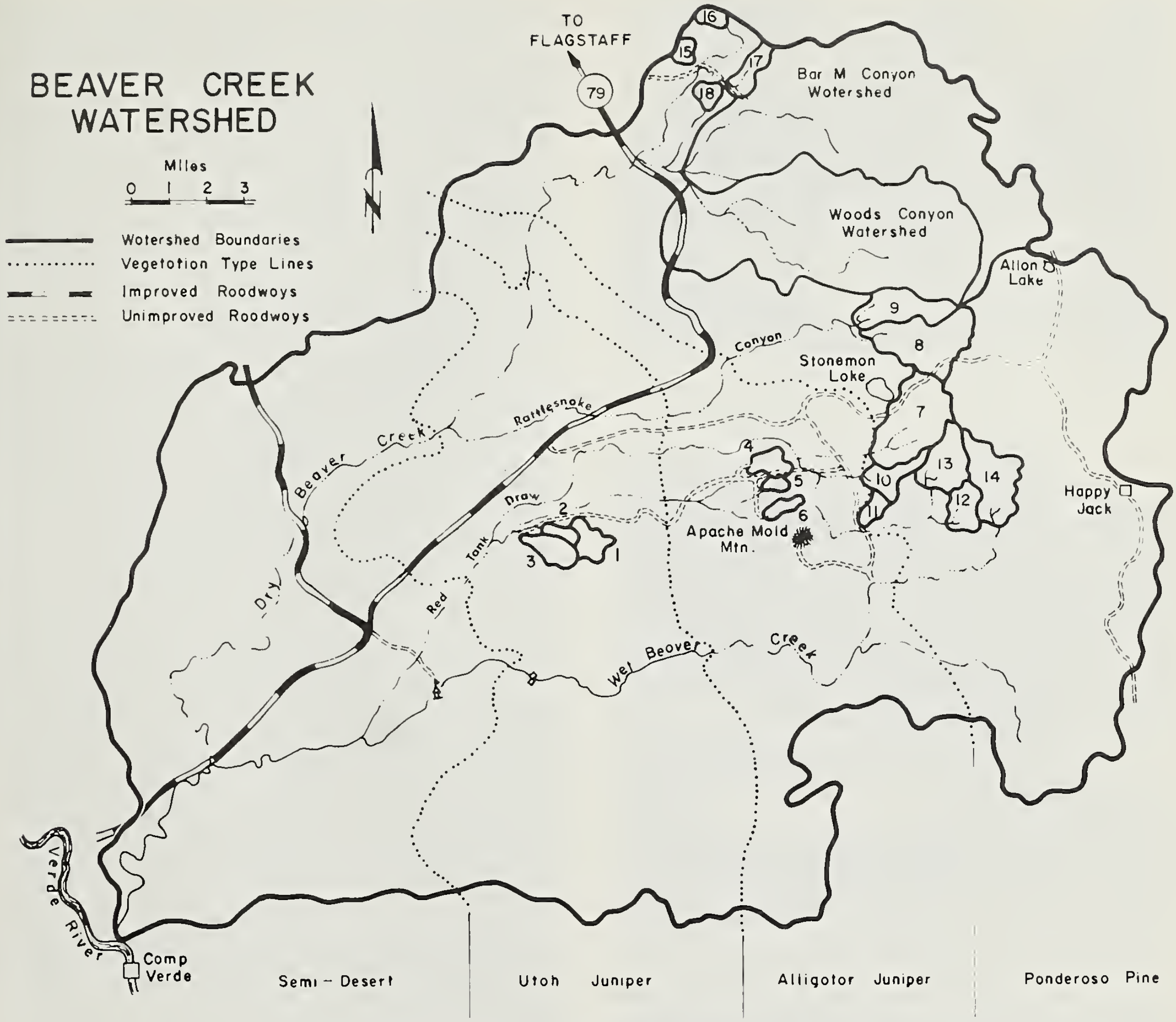

Figure 2.—The Beaver Creek Pilot Watershed.

watershed. It begins with a general description of the temperature and precipitation regimes, and then follows precipitation as it falls on a watershed to its eventual disposition as runoff, evaporation, transpiration, or subsurface flow.

Temperature.—The Beaver Creek watershed lies in the center of Arizona in what is called the plateau climatic region, which includes the Kaibab, Coconino, and Mogollon Plateaus and the San Francisco and White Mountains (Green and Sellers 1964). January temperature in the region averages 26° F and the July temperatures 66° F (Schubert 1974).

Climatic records of different kinds are presently being obtained at 50 locations in the pine type on Beaver Creek. At ten of the locations precipitation is recorded continuously. Temperature and humidity are recorded at three locations. Average annual temperature in the pine type has been 45° F. Monthly averages have been as follows:

	Maximum	Minimum	Mean
		(Degrees F.)	
October	64	30	47
November	52	23	37
December	44	15	29
January	44	14	29
February	45	16	30
March	49	19	34
April	56	24	40
May	67	31	49
June	76	37	57
July	83	48	66
August	78	47	63
September	73	41	57

These data are based on an average of 12 years of record from weather stations on Watersheds 8, 17, and Bar M.

Precipitation.—The ponderosa pine type in Arizona receives between 15 and 25 inches of precipitation annually (Schubert 1974). On Beaver Creek the average annual precipitation has ranged from 18 to 35 inches with an average of 25 inches on six representative watersheds. These watershed averages, based on 13 years of record, were determined by the Theissen method using 20 precipitation gages. Precipitation distribution throughout the water year is illustrated by these monthly averages for Watersheds 7, 8, 10, 13, 15, and 18:

	Inches
October	1.08
November	2.40
December	3.65
January	2.10
February	2.25
March	2.59
April	1.83
May	.65
June	.44
July	2.34
August	3.22
September	2.41
Average annual	24.96±0.61

There are two major precipitation seasons in the plateau region. The most important is during the winter — October through April. Sixty-four percent of the annual precipitation falls during these 7 months on Beaver Creek. The second is during the summer, particularly July through September, during which 32 percent of the annual precipitation falls.

Predictable atmospheric circulation patterns carry large quantities of moisture over the State and encourage precipitation. Moisture for most summer precipitation comes from the Gulf of Mexico. Occasional record summer rains in the past century have been associated with movements of tropical air into the State from the Gulf of California and the Pacific Ocean. Moisture for winter precipitation comes from the Pacific Ocean.

Average annual snowfall for 15 locations in the ponderosa pine forests of Arizona ranges from a low of 12 inches to a high of 94, with an annual mean of 46 inches (Schubert 1974). Snowfall is not consistent from year to year in this area. Fort Valley averages 91 inches, however in 13 out of 60 winter seasons less than 60 inches of snow fell. Snowfall during 34 percent of these winters averaged less than 1 foot per month for four consecutive months.

The snow regime as described by the SCS snow courses at Casner Park, Happy Jack, and Munds Park provide a usable estimate of the snow conditions on Beaver Creek. The 15-year average water equivalents at these locations on March 1 are 3.2, 4.4, and 2.7 inches, respectively, or 3.4 inches overall. This compares to 3.6 inches at Heber and Workman Creek, Arizona. The snow regimes on Beaver Creek are characteristic of locations along the Mogollon Rim; however, they are higher than pine areas away from the Rim such as Fort Valley, which has an average of 2.1 inches.

Snow regimes on Beaver Creek are quite variable and result in different runoff patterns and amounts. Most runoff is produced when there is a continuous snowpack from November through April. In these years there is often a continuous small flow of water from the pine watersheds, followed by a large runoff period in March or April. Often, major runoff occurs when rain falls on a snowpack. In Water Year 1966 there was almost continuous flow all winter as a result of intermittent storms which dropped mixed precipitation — both rain and snow — on a shallow snowpack. In Water Year 1972 a snowpack started to accumulate in November and built up till late in December when a rainstorm removed all of the snow, producing a large runoff event. A third type of snow regime is characterized by intermittent snowfall followed by a dry period in which the snowpack disappears. These typically light snowfall years yield little if any runoff since most of the water in the snow evaporates back to the atmosphere or infiltrates into the soil. In a fourth snow regime, very little snowfall occurs throughout the season. During these winters the snowpack seldom accumulates over a few inches, and results in little if any runoff.

Interception, stemflow, and throughfall.—Studies of rainfall interception by pole-sized ponderosa pine in central Arizona have shown that 11 to 25 percent of the summer rainfall is intercepted (U.S. Forest Service 1958). Of the net rainfall (throughfall plus stemflow), 71 to 88 percent reaches the soil as throughfall and 1 to 8 percent is transported to the soil as stemflow. Although little is known about interception of snow by ponderosa pine on Beaver Creek, Kittredge (1948) reported 22 percent interception by mature ponderosa pine in Idaho and 18 percent for young ponderosa pine in Colorado (Kittredge considered interception to include stemflow). Thus ponderosa pine apparently intercepts similar percentages of snow and rain.

Evaporation.—Studies of evaporation from forest floor litter under ponderosa pine in cen-

tral Arizona show that between 7 and 25 percent of the total summer rain is evaporated to the atmosphere (U.S. Forest Service 1959).

Studies of evaporation from snow under ponderosa pine in Arizona and New Mexico show that between 0.006 and 0.16 inch of water per day is lost to evaporation (U.S. Forest Service 1960). Thus a snow cover present for 2 months may lose as much as 5 inches of water by evaporation. In open areas within the forest, this amount would probably be greater.

Infiltration.—The major soil series in the ponderosa pine area on Beaver Creek are Brolliar, Siesta, and Sponseller. These soils are developed on parent materials of basalt and volcanic cinders. Their textures range from moderately fine to fine, and they characteristically have a slow rate of infiltration — 0.05 to 0.2 inch per hour when thoroughly wetted (Williams and Anderson 1967). These soils also have a layer that impedes downward movement of water. These characteristics are major factors in producing the surface runoff which comprises most of the water yield on the Beaver Creek watersheds.

Streamflow.—New techniques in streamgaging have been utilized on Beaver Creek to accurately measure the broad range of debris-laden discharges carried by the streams. A concrete trapezoidal flume was designed for use on the 18 small watersheds. The design was a modification of a Washington State College flume, adapted to Beaver Creek conditions (fig. 3).[4] Another was a new design for gaging discharges of several thousand ft^3/s (cubic feet per second) on Woods Canyon and Bar M (fig. 4; Brown 1969). H flumes have been constructed on 24 small homogeneous subwatersheds where flows are usually less than 15 ft^3/s (fig. 5).

The watersheds are organized into an experimental design to provide a basis for statistical evaluation of changes in streamflow. Watersheds within each vegetation type are paired, with some scheduled for treatment and others retained untreated as statistical controls. Following pretreatment calibration, one watershed in each pair is treated. These methods are described by Kovner (1956), Kovner and Evans (1954), and Wilm (1943).

Average annual streamflow from all untreated pine watersheds on Beaver Creek has varied from 0.2 to 16.4 inches with an overall average for the type of 5.3±0.5 inches per year (based on 14 years of record, through Water Year 1973). Ninety-three percent of this flow has come during the period October through April as a result of snowmelt or winter rains.

[4]*Robinson, A.R. Study of the Beaver Creek measuring flumes. Report to the Rocky Mt. For. and Range Exp. Stn. 14 p. Flagstaff, Ariz.*

Figure 3.—Concrete trapezoidal flume of the type used on Watersheds 1-18 on Beaver Creek.

Figure 4.—The Woods Canyon streamgage.

Figure 5.—Streamgaging installation used on subwatersheds.

Occasional summer storms produce flood flows of short duration. Although these floods do not contribute much to the total water yield they are a major factor in erosion and sedimentation.

Figure 6 illustrates the monthly distribution of streamflow and precipitation (based on 112 station years of record). For the year as a whole, 20 percent of the precipitation becomes streamflow. For the October-April period, streamflow is 28 percent of precipitation, and for May-September it is 3 percent.

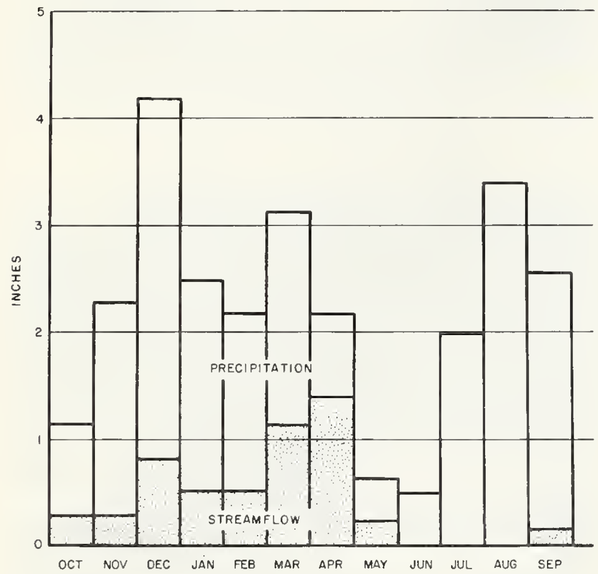

Figure 6.—Distribution of precipitation and streamflow on the Beaver Creek ponderosa pine watersheds.

Sediment.—Sediment yield data have been obtained by means of catchment basins and splitting devices installed on Watersheds 9, 10, 12, 14, 16, and 17. These installations (fig. 7) are described in detail by Brown et al. (1970). Suspended sediment concentrations have also been sampled intensively on all watersheds. Approximately 1,000 samples have been analyzed, and the results are to be reported in a later publication.

Mean annual sediment yields from untreated pine watersheds (26 station years) have varied from a trace (less than 0.005 ton per acre) to 6 tons per acre, with an average of 0.6 ton per acre over an 11-year period of record. This average, however, should not be used to characterize total yields from pine areas because it is influenced heavily by the 100-year storm of September 5, 1970. Excluding this extreme event, annual sediment yields have averaged only 0.02 ton per acre.

Except for the September 1970 storm, essentially all sediment has been produced during winter seasons. Winter sediment yields have ranged from a trace to 0.06 ton per acre with an average of 0.02 ton per acre.

Sediment yields from individual untreated watersheds have ranged from a trace to 11 tons per acre during the 11-year period of record. The 11 tons per acre were derived from Watershed 10 during the September 1970 storm which produced a peak streamflow discharge of 1,090 $ft^3/s/mi^2$ with an estimated recurrence interval of over 200 years.[5] This watershed was within or near the center of maximum 30-minute precipitation intensity and total storm precipitation, 3.0 inches per hour and 7.0 inches, respectively.

The only peak discharge recorded on Beaver Creek which exceeds the amount in this storm was from a 3-year-old clearcut on Watershed 12 which had a discharge of 1,200 $ft^3/s/mi^2$ and a sediment yield of 9 tons per acre. Clearcutting in this case appears responsible for the high peak discharge and resulting high sediment yield.

On untreated Watershed 10 the high streamflow was apparently due to the high precipitation intensities. Contributing further to the high sediment yield was the apparent accumulation of sediment available in its channels; during its 7-year period of record it had never produced more than 0.03 ton per acre. Therefore, potential sediment yields of at least 11 tons per acre may be realized from individual untreated pine watersheds with characteristics similar to those found on Beaver Creek.

[5]*Based on estimates made by the U.S. Geological Survey.*

Figure 7.—Installation for obtaining sediment yield data. Coarser sediments are caught in the basin above the dam, while suspended sediment is sampled continuously by a series of three splitters.

Water Quality

Quality of runoff water has been analyzed since 1969. Only occasional samples have been collected and sampling conditions have varied. Most samples were of runoff from a melting snowpack. An exception was a group of four samples from the September 5, 1970, storm. Samples were taken at the flumes, either dipped or with a DH-48 sampler.

Average values for key water quality characteristics on untreated pine watersheds are summarized as follows:

Ion	Concentration *Mg/l*
TDS	44
Ca	5.1
Na	1.9
PO_4	.16
NO_3	.16
Fe	.29

Electrical conductivity ranged from 38 to 65 μ mho/cm. Sodium was low, with SAR (sodium absorption ratio) below 0.2 on all samples. No one watershed produced water of consistently different quality than any other. Water from the pine watersheds met quality standards for drinking water, aquatic life, and irrigation (National Technical Advisory Committee, FWPCA 1968). Only iron approached the unacceptable level for drinking water.

Timber

A comprehensive description of the timber stands on Beaver Creek is essential to this presentation, because results of the treatments and predictions produced by the current models are most applicable to these kinds of forest stands.

The forest on Beaver Creek is composed of a mixture of ponderosa pine (*Pinus ponderosa* Laws.), Gambel oak (*Quercus gambelii* Nutt.), and alligator juniper (*Juniperus deppeana* Steud.) with a combined basal area of 115 ft^2/acre. Pine basal area averages 92 ft^2, Gambel oak 18 ft^2, and alligator juniper 5 ft^2. Volumes of typical untreated stands average 2,050 ft^3/acre overall, of which 1,775 ft^3 are pine (Myers 1973), 230 ft^3 Gambel oak (Gevorkiantz and Olsen 1955), and 45 ft^3 juniper (Howell and Lexen 1939). Average board-foot volume of ponderosa pine is 4,070 fbm/acre (Ffolliott et al. 1971) of which only 5 percent are in grade 3 saw logs or better. Average growth of pine stands is 40 ft^3 or 75 fbm/acre/year.

The number of trees per acre by size class (table 1) is important because it characterizes the typical stand. There is an excess of trees in the 2- through 10-inch and 26-inch plus classes, and a shortage of trees in the 14- through 24-inch classes. Average site index (height in feet at 100 years) is 60 (Meyer 1938).

Table 1.--Average number of trees per acre, by species and diameter class, on Beaver Creek watersheds 8-10 and 12-18

Diameter class (*Inches d.b.h.*)	Ponderosa pine	Gambel oak	Alligator juniper[1]	Quaking aspen	All species
			Number		
Reproduction	174.67	82.91	4.95		262.53
2	349.83	40.65	19.73	0.24	410.45
4	90.88	20.13	4.98	.03	116.02
6	51.09	12.66	1.05	.02	64.82
8	36.66	5.46	.38		42.50
10	23.66	3.73	.10		27.49
12	12.39	2.99	.12		15.50
14	6.31	1.76	.05		8.12
16	2.60	1.03	.12		3.75
18	2.02	.74	.09		2.85
20	1.32	.47	.07		1.86
22	1.21	.20	.04		1.45
24	.97	.11	.09		1.17
26	.70	.06	.07		.83
28	.52	.02	.07		.61
30	.28	.01	.05		.34
32	.13		.02		.15
34	.07		.03		.10
36	.03		.04		.07
38	.01		.04		.05
40	.01		.01		.02
42			.01		.01
44			.02		.02
46			.01		.01
48			.01		.01
50			.02		.02
Total[2]	580.69	90.02	27.22	.29	698.22
			Percent[2]		
	83.17	12.89	3.9	.04	100.00

[1]Includes all *Juniperus* species.
[2]Exclusive of reproduction.

The inventory system used on Beaver Creek went beyond the standard estimates of volume, basal area, and number of trees per acre, to include timber quality data describing basic stem characteristics and defect features that influence quantity and quality for most primary products (Barger and Ffolliott 1970). Further refinements allow levels of stocking (Ffolliott and Worley 1973) to be calculated, such as the percent of the area stocked to 50 ft^2 basal area in trees 18 inches or larger. From these stocking

levels, timber stocking, recreation potential, or forage production can be determined (Ffolliott and Worley 1965).

The number of trees per acre and site index are used to initialize the timber simulation model described in a later section. Growth information will be used to validate model predictions. Basal area is the stand density parameter used in production functions because of its effects on other products such as runoff, sediment, and forage yields.

Range

Total herbage production in the pine type on Beaver Creek averages 198 pounds per acre annually for untreated conditions, consisting of 124 pounds of perennial grasses, 58 pounds of forbs and half-shrubs, and 16 pounds of shrubs. Following are the major herbaceous and shrubby species occurring under ponderosa pine stands (average pretreatment values for Watersheds 8, 9, 10, 12, 13, 14, and 17 based on 2 to 9 years of record):

Grasses and grasslike plants	Pounds per acre
Bluegrass, mutton (*Poa fendleriana*)	23
Dropseed, black (*Sporobolus interruptus*)	10
Grama, blue (*Bouteloua gracilis*)	23
Sedge (*Carex* spp.)	6
Squirreltail, bottlebrush (*Sitanion hystrix*)	46
Others	16
Forbs and half-shrubs	
Aster, showy (*Aster commutatus*)	3
Fleabane, spreading (*Erigeron divergens*)	4
Fleabane, trailing (*E. flagellaris*)	3
Goldeneye, showy (*Viguiera multiflora*)	3
Ragweed, western (*Ambrosia psilostachya*)	7
Snakeweed, broom (*Gutierrezia sarothrae*)	3
Wormwood (*Artemisia carruthii*)	3
Others	32
Shrubs	
Locust, New Mexican (*Robinia neomexicana*)	3
Oak, Gambel (*Quercus gambelii*)	13
Total	198

The range inventories on Beaver Creek originally involved only transect measurements of condition and trend, and plot measurements of production and utilization. Such measurements have been made periodically at 10 locations within Watersheds 7 through 14. At each location there is a cluster of ten 9.6-ft^2 herbage production and utilization plots and two 100-foot Parker 3-step transects. Herbage production is determined for each species by weight estimate and checked by clipping and weighing (Pechanec and Pickford 1937a). Forage utilization is determined by the ocular-estimate-by-plot method (Pechanec and Pickford 1937b). Ground cover and plant frequency are determined by the method of Parker (1954). The Parker transects aid in determining the ecological impact of the different treatments on plant composition and soil stability.

These conventional methods of range inventory, however, do not lend themselves to statistical sampling of large diverse areas. Thus it became necessary to measure herbage production at the timber inventory plot locations and to develop relationships between herbage production and more easily measured site characteristics of tree density and cutting history, soils, topography, forest floor characteristics, and composition and distribution of the forage. Some of these relationships are described by Clary (1964, 1969); Clary and Ffolliott (1966, 1969); Clary, Ffolliott, and Jameson (1968); Clary, Ffolliott, and Zander (1966); and Clary and Pearson (1969) (see later section on modeling). In addition, special studies have been initiated to characterize range response following unique treatments such as stripcutting and burning.

Wildlife

Big game use on Beaver Creek is measured in cooperation with the Arizona Game and Fish Department. Changes in the deer and elk use are estimated from counts of fecal droppings on plots superimposed on the timber inventory sample. Forage preferences of deer are determined by observing the plants eaten by tame deer under different treatment conditions. Production of preferred wildlife forage is determined by combining species yields and preference information. Observational studies have been conducted to determine the response of wild deer to different treatment situations. Hunter check stations and traffic counters have yielded information on the social and economic significance of the game resource.

Big game numbers have declined drastically on Beaver Creek throughout the period of the study, as they have in Arizona and the Southwest as a whole. Deer and elk populations calcu-

lated from Neff's 1959-60 data (Neff 1972) were 9 and 3 per section, respectively. During the period 1965 to date deer populations on untreated watersheds have been approximately 0.9 per section and elk 1.3 per section.

The forage plants on untreated areas that are most preferred by deer include, in order of preference (Neff 1974):

	Percent of deer diet
Gambel oak (*Quercus gambelii*)	38
Unidentified immature grasses	7
Ponderosa pine (*Pinus ponderosa*)	5
Redroot eriogonum (*Eriogonum racemosum*)	4
Geranium (*Geranium* spp.)	4
Clover (*Trifolium* spp.)	3
Milkvetch (*Astragalus recurvus*)	2
Mountainmahogany (*Cercocarpus* spp.)	2
Red-and-yellow pea (*Lotus wrightii*)	2
	67

Because of concern over environmental issues, the wildlife program on Beaver Creek was expanded in 1972 to include studies of birds, insects, carnivores, and desert cottontail, Abert's squirrel, and other forest rodents. The ultimate goal will be to describe the interactions between all major forest fauna and other ecosystem components under a variety of management conditions. The latter research is being conducted in cooperation with Northern Arizona University, the University of Arizona, and the Museum of Northern Arizona.

Esthetics

Much of the esthetic quality of forest lands can be attributed to the physiographic, climatic, and vegetative characteristics of the area. The ponderosa pine forests of Arizona are situated in an intermediate position between the State's widespread desert and woodland regions and its higher (but widely separated) montane forests of aspen and mixed conifers. Because this intermediate zone has a vigorous climate with relatively large seasonal variation, it provides a welcome visual relief for travelers and recreationists from other parts of the State. Its potential as an area of high scenic value was suggested by an 1858 military report:

> It is the most beautiful region I ever remember to have seen in any part of the world. A vast forest of gigantic pine, intersected frequently with open glades, sprinkled all over with mountains, meadows and wide savannahs, and covered with the richest grasses, was traversed by our party for many days (Lt. E.F. Beale, quoted by Cooper 1960).

The regional geology is such that the south-trending formations of the Colorado Plateau direct groundwater to feed several perennial streams which begin in an otherwise arid environment below the Mogollon Rim. Above the Rim on the plateau, a number of well-defined but in some cases ephemeral streams begin, which feed either the Little Colorado River or the Salt-Verde systems.

The Beaver Creek study area includes watersheds in both the woodland and the intermediate zones. Although the pine watersheds are above the Rim topographically, they nevertheless drain southward to the Salt-Verde River system and all of them contain ephemeral streams.

Litton (1968) developed the concept of characterizing landscapes or segments of landscapes by means of definable terms such as "panoramic," "feature," "enclosed," "focal," "canopied," "detail," and "ephemeral." Landscapes can be also described as either "macro," extending far into the distance, or "micro," where visibility is restricted to a matter of yards (U.S. Forest Service 1973).

Using this terminology we can briefly characterize the landscape of the ponderosa pine type on Beaver Creek, while considering at the same time the possible implications of several forest management practices.

These lands generally afford few, if any, **panoramic landscapes**. They are too flat, too covered with forest trees to provide vistas of the rolling distant countryside. Such a landscape could only be seen by ascending local promontories, and few locations provide this opportunity.

Stoneman Lake, a caldera, and Apache Maid Mountain provide outstanding **feature landscapes** in the study area. Distinct, visually important landscapes are relatively few on this uniform plateau.

Significant "macro" landscapes are provided at locations where one can look out across the Verde Valley — which suggests the opportunities for enhancing these views by carefully planned forest clearing along certain roadways.

The glades surrounded by forest referred to by Lt. Beale, may be what are now known locally as "cienegas" or "parks." Litton would call these **enclosed landscapes**: they are defined by their "wall" and "floor" characteristics. Land managers can create enclosed landscapes by cutting harmonious forest openings. **Focal landscapes**, on the other hand, can occur anywhere

that roads, landforms, vegetative patterns, or waterways lead the observer's eye to a point of convergence.

Canopied landscapes, characterized by immediate overhead trees, abound for the hiker in the ponderosa pine forest but are observed by the motorist only when he is travelling narrow, unimproved roads.

Detail landscapes, tied to minute segments of the immediate foreground, are an important consideration in making esthetic evaluations of forest treatments. It is the "micro" component of the landscape which includes such things as the bole of a mature ponderosa pine tree, lichen-covered rocks, or bracken fern on the forest floor. It can also include the slash, stumps, and soil disturbance that typify some cutover areas.

Ephemeral landscapes exist only for a brief period. Their creation and disappearance are generally caused by climatic or phenological events such as sunsets and autumnal coloration. The Gambel oaks, aspen, and occasional maples associated with the pine forests provide an abundance of fall colors which are widely appreciated in Arizona. Likewise the effect of man may be ephemeral, depending on the permanence of his impact.

Other concepts of landscapes quality dealing with "variety," "deviations," and "contrast" (U.S. Forest Service 1973) also have implications for forest treatments. Since they imply changes in forest cover, however, we will deal with them under treatment responses.

Many people feel that quality landscapes are characterized by a pleasing degree of variety, with the various components of the landscape appearing to be in harmony with each other. Harmony demands that variety be of a compatible size scale; also, it is important that small-scale variations should not be repeated indefinitely, nor should large-scale variations be easily recognized. These concepts are obviously quite subjective.

The overall landscape quality of this pine area, although pleasing, can be improved. It can also be damaged by inappropriate land management practices. Like other resources, the scenic resource requires sound investments guided by skillful management in order to attain its potential value, especially in view of the increasing and competitive demands being made on the forests of the Rim Country.

Treatment Tests

Seven treatments are presently being evaluated in the pine type on Beaver Creek. Two more are scheduled in 1974. With one exception, a wildfire, all treatments are on calibrated watersheds. All are timber overstory removal treatments except for grazing.

The earlier treatments were designed to increase streamflow, but were evaluated in multiple use terms. The two most recent treatments, on Watersheds 14 and 16, incorporated numerous features to enhance timber, wildlife, and esthetic values. The two treatments scheduled in 1974 are designed primarily to enhance wildlife (Watershed 10) and timber (Watershed 8). The early treatments have been described by Brown (1970, 1971) and O'Connell and Brown (1972).

Two basic kinds of timber overstory removal are considered: thinning and cleared openings. Different basal areas and spacing of openings are being tested to evaluate a range of treatment intensities. Clearing all the woody vegetation is being tested as the most severe level of treatment to determine maximum possible water yields.

With the recent shift of objectives toward development of multiple use management models, the treatments are now viewed as providing validation data for mathematical models that can be used to estimate treatment response for a wide range of conditions. These models will be discussed in a later section.

Description of Treatments

Thinning by group selection on Watershed 17 in 1969 (fig. 8).—Seventy-five percent of the initial 120 ft^2 basal area was removed by thinning, leaving evenaged groups with average basal areas of 30 ft^2/acre (basal areas are total, for all species). All Gambel oaks over 15 inches d.b.h. except den trees were removed, leaving 5 ft^2/acre of oak basal area; all alligator junipers were removed. The slash was windrowed. Theoretically, the treatment would be repeated every 20 years.

Stripcut for water yield on Watershed 9 in 1967-68 (fig. 9).—Thirty-two percent of the watershed was clearcut in uniform strips 60 feet wide, and slash was pushed to the center of cut strips and partially burned. Spacing between cut strips is 120 feet. Pretreatment basal area, all species, was 119 ft^2/acre; posttreatment was 81 ft^2. Cut strips will be allowed to restock naturally. The area between cut strips was not treated. The treatment is theoretically planned to be repeated every 40 years, so that in a rotation of 120 years the whole watershed would be cut.

Strip shelterwood cut on Watershed 14 in 1970-71 (fig. 10).—One-third of the watershed was cleared in irregular cut strips averaging 60 feet wide. Intervening leave strips which average 120 feet wide were thinned to 80 ft^2 basal area by a silvicultural cut favoring tree diameter classes that are in short supply on the Coconino National Forest. The original basal area of all species was 121 ft^2/acre; the post-treatment basal area was 60 ft^2 overall, yielding an overall reduction of 50 percent. Heavy concentrations of slash from leave strips were pushed into piles in the cut strips and burned. Pine seedlings were planted in the cut strips on better sites. Esthetic areas were preserved from any treatment, and Gambel oaks less than 15 inches d.b.h. were left in both cut and leave strips to benefit wildlife and esthetics. Trees will be thinned back to 80 ft^2/acre at 20-year intervals, and new strips will be cut at 40-year intervals.

Strip shelterwood cut on Watershed 16 in 1971-72.—Fifty percent of the watershed was cut in irregular strips averaging 60 feet wide. In the intervening leave strips, which also average 60 feet wide, the trees were thinned to 80 ft^2 basal area. Sixty-five percent of the basal area was removed overall. Gambel oak and slash were treated as in Watershed 14. Esthetic areas were preserved from any treatment. At 20-year

Figure 8.—In 1969, 75 percent of the basal area was removed on Watershed 17 in a heavy thinning treatment.

Figure 9.—One-third of Watershed 9 was cleared in 60-foot wide strips, with no treatment of the intervening areas. The strip width was chosen to maximize trapping and retention of snow. The strips were oriented to lead water directly into the streams.

intervals the stands will be thinned back to 80 ft^2/acre of basal area, and at 60-year intervals the alternate strips will be cut.

Total clearcut on Watershed 12 in 1966-67 (fig. 11).—This watershed was essentially removed from timber production. The slash was windrowed and oak sprouts were partially controlled with chemical sprays. While some natural restocking is taking place, it will be many years before any timber-oriented work will be done unless the area is planted. This treatment is not intended to have operational potential but rather is an analytical benchmark against which to compare less severe treatments.

Grazing on converted Watershed 11 (fig. 12).—Sixty percent of the perennial grass on the watershed has been utilized by cattle grazing in the spring and fall, starting in the fall of 1967. The watershed had been converted from pine to grass in 1958.

Wildfire of severe and moderate intensities in 1972.—The effects of wildfire are being studied on two small uncalibrated watersheds, one burned severely and the other moderately. The Rattle Burn fire occurred in the spring of 1972, 30 miles southwest of Flagstaff. Shortly afterwards three small watersheds were instrumented, two on the burn and one nearby for a control. Special emphasis in the evaluation of this treatment is being placed on wildlife effects, nutrient movement, and water infiltration into the soil.

Treatment Responses

Streamflow responses have been evaluated on six Watersheds: 12 —clearcut; 9 —one-third regular stripcut; 17— three-fourths thin; 14— one-third irregular stripcut and thin; 16— one-half irregular stripcut and thin; and 11— grazing. Total **sediment** yield has been evaluated only on Watersheds 12, 9, 17, 14, and 16. An unusually large storm in September 1970 provided an additional basis for evaluating flood response on Watersheds 12, 8, 17, and 11. Intensive suspended sediment sampling provides the only basis for evaluating sediment from the grazing treatment on Watershed 11. **Herbage** responses have been intensively evaluated on Watersheds 12, 9, and 11. Herbage production models, now under development, will be used later to predict responses to the other treatments.

Streamflow.—Responses of winter streamflow to the vegetative treatments on the pine watersheds are summarized in table 2. Mean winter streamflow for the untreated condition is based on variable periods of record, and has been adjusted by covariance to minimize uncontrolled variation due to climate and other factors not associated with treatment (Kovner 1956, Kovner and Evans 1954, Wilm 1943). This analysis is designed to detect treatment responses of greater than 15 percent at appropriate risk levels. Responses for individual years following treatment are determined by sub-

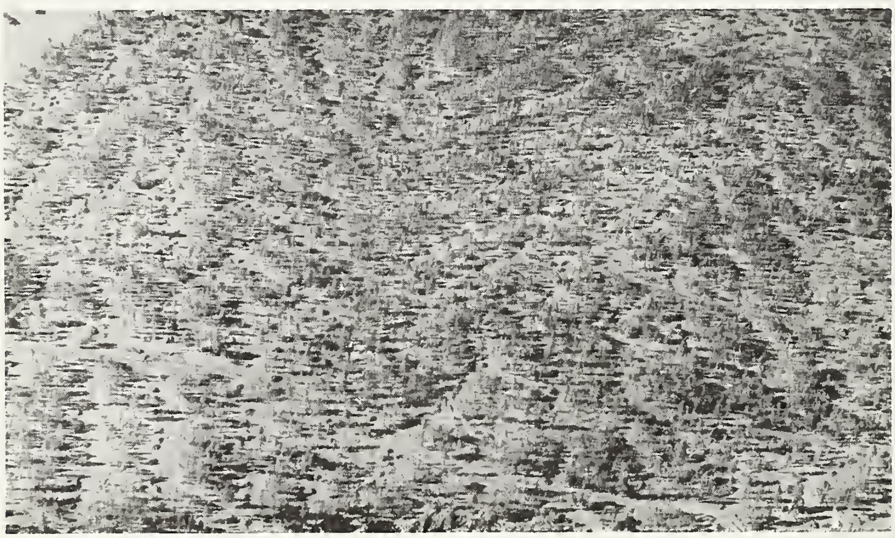

Figure 10.—One-third of Watershed 14 was cleared in 1971 in a pattern of irregular strips which vary in width from 30 to 90 feet. The intervening strips have been thinned to 80 ft^2 basal area to improve timber growth. The cut strips on better sites have been planted to assure continued timber production. Oak trees are left standing in the cut strips to enhance esthetic and wildlife values. Three especially attractive "esthetic areas" were not treated.

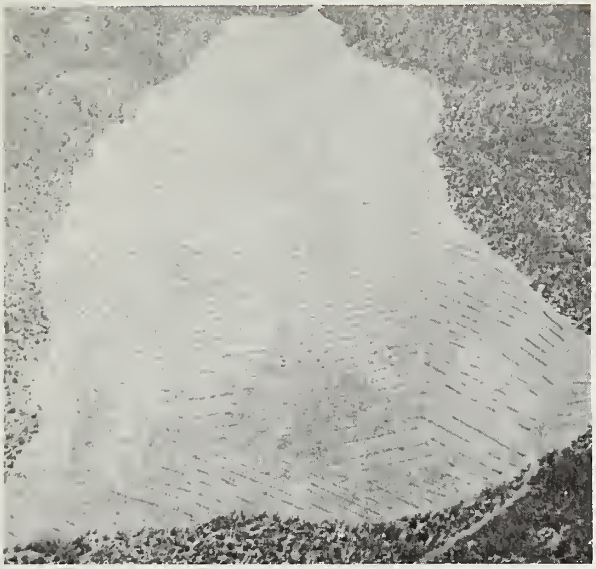

Figure 12.—A treatment started in 1967 on Watershed 11 is designed to determine whether more streamflow is produced under 60 percent grazing use than under no grazing.

Figure 11.— Aerial view of pine clearcut on Watershed 12. The slash was windrowed in a pattern to trap snow and expedite water movement into the streams.

Table 2.--Summary of effects of treatments on winter streamflow from the pine watersheds

Watershed, by treatment, and year treatment completed		Untreated mean winter streamflow[1]	Difference between actual and predicted streamflow by years following treatment[2]						Mean difference	Percent difference	Level of significance
			1st	2d	3d	4th	5th	6th			
Watershed 12-- 100% clearcut	1967	6.04	3.79	0.92	1.81	1.47	1.39	3.29	2.03	34	0.01
Watershed 9-- 32% clearcut in uniform strips	1968	6.70	1.98	.61	.34	.84	1.74		1.10	16	.05
Watershed 11-- 60% utilization of perennial grass	1967	3.16	.34	.24	.11	.29	-.20	.78	.26	8	([3])
Watershed 17-- 75% thin	1969	7.63	.85	1.45	1.51	2.93			1.68	22	.05
Watershed 14-- 33% pine clearcut in irregular strips, thinning between strips; 50% basal area removed overall	1970	4.71	.71	.70	1.61				1.01	21	.05
Watershed 16-- 50% clearcut in irregular strips, thinning between strips; 65% basal area removed overall	1972	5.45	5.60						5.60	103	.01

[1] Adjusted by covariance for years 1960-73 for watersheds 12, 9, 14; 1961-73, watershed 11; 1963-73, watersheds 16 and 17.
[2] Predicted streamflow is that which would be expected to occur in a given year had the watershed not been treated.
[3] Not significant at 0.05 level.

tracting the flow that would be predicted to occur, assuming pretreatment vegetative conditions, from the actual. Average treatment responses are expressed quantitatively in inches and as a percent of the pretreatment mean.

The largest response in winter streamflow was from an irregular stripcut and thinning treatment on Watershed 16 which removed 65 percent of the timber basal area. The response averaged 5.6 inches or 103 percent for the first year after treatment, and was significant at the 1 percent level. This very large response should be interpreted with caution. It is partially the combined result of the unusually wet 1973 winter and the large increase that is usual the first posttreatment year. The theory behind the irregular stripcut and thin treatment is that decreased water loss by transpiration and increased efficiency of runoff transport in the cut strips will increase water yield from the watershed. More efficient waterways for transporting surface runoff into the channels are believed to be formed by orienting cut strips perpendicular to the slopes and by reducing the soil water deficit through tree removal. More snow should also reach the ground in the cut strips due to reductions in interception losses and in redistribution of snow by the wind. The snowpack in the east-west oriented strips is partially shaded, thus reducing evaporation losses during the winter. This also produces more efficient runoff by delaying melt until the ambient temperature is relatively high.

The second largest response in winter streamflow came from the 100 percent clearcut on Watershed 12. The runoff increase averaged 2.0 inches per year or 34 percent over a 6-year period, and was significant at the 1 percent level. The increased water yield from this clearcut treatment is primarily due to a decrease in water loss by transpiration. By reducing the soil moisture deficit on the watershed, more runoff is realized from the melting snowpack. In addition, the windrowed slash traps snow and delays melt rates on the lee side. With delayed snowmelt, snow remains on the watershed until the ambient temperature rises high enough to melt the snow rapidly, and more surface runoff thereby reaches the channels. The efficiency of surface runoff transport is also increased because the windrows, which are directed downslope, shade the soil on their lee side. This reduces soil moisture loss and provides more efficient waterways for transporting surface runoff into the channels.

The third largest response resulted from the removal of 75 percent of the timber basal area by thinning on Watershed 17. The average increase was 1.7 inches per year or 22 percent for a 4-year period, and was significant at the 5 percent level. Again the response is apparently due largely to greater efficiency in surface runoff and reduced transpiration loss. The residual slash was piled into windrows and had an influence on the snowpack similar to that on the clearcut Watershed 12.

Watershed 14, which was stripcut and thinned, provided a 1.0 inch per year or 21 percent response over a 3-year period, significant at the 5 percent level. Watershed 14 can be expected to behave similarly to Watershed 16 but probably not as efficiently because only a total of 50 percent of the timber basal area was removed.

Watershed 9 had 32 percent of its timber removed in uniform downslope strips. Streamflow increase was 1.1 inches per year or 16 percent over a 5-year period, significant at the 5 percent level. Watershed 9 is expected to behave similarly to Watersheds 14 and 16. The vegetation treatment differs on Watershed 9 in that the cut strips are uniform in width, the leave strips were not thinned, and no oak trees were left in the cut strips.

Watershed 11, which has been grazed after conversion to a grass cover, shows only an 8 percent increase after a 6-year period. This increase is not statistically significant at the 5 percent level, and does not approach practical importance. It was theorized when this treatment was planned that grazing might reduce herbaceous plant growth and result in an increase in water yield due to reduced transpiration losses. It was also thought that compaction of the soil by the cattle might contribute to the efficiency of surface runoff. Plant growth has changed negligibly, however, (see table 5), and soil compaction apparently was not sufficient to produce an important increase in surface runoff.

A special commentary is in order regarding the unusually wet winter of 1972-73, and its effect on watershed treatment responses. The highest previously recorded winter precipitation for pine watersheds on Beaver Creek was in water year 1965, and ranged from 21 to 28 inches. The resulting runoff was also the previous high on record, ranging from 6.3 to 14.1 inches. In the winter of 1972-73 these watersheds received between 32 and 41 inches or an average of 1.5 times more precipitation than in 1965. Runoff was 11.1 to 27.8 inches or an average of 1.8 times more than the previous high. Responses to treatment during water year 1973 exceeded all but the first-year responses on Watersheds 9 and 12 (table 2).

Flood peak.—The major storm which struck Beaver Creek in September 1970 provided an opportunity to assess the effect of the pine

treatments on flood peaks.[6] Estimates of treatment effects are summarized in table 3. These responses were determined graphically, based on the relationship between peak discharge and 60-minute precipitation intensity (fig. 13). The assumption here is that the departures of a treated watershed from the untreated watershed relationship represent a treatment response. Table 3 also contains the estimated recurrence intervals for the observed peak discharges.

Peak discharge increased most — 750 $ft^3/s/mi^2$ — on Watershed 12. The second largest response was 400 $ft^3/s/mi^2$ from Watershed 11, which had been clearcut and seeded to grass in 1958, 12 years prior to the storm.

Responses which were apparently due to the complete or large reduction in timber and associated litter cover from Watersheds 11, 12, and 17 ranged from 350 to 750 $ft^3/s/mi^2$, or about twice the peak discharge expected from an untreated watershed with similar precipitation intensity. On the average, 92 percent of the timber basal area had been removed from these watersheds. They were subjected to 5.6 inches total rainfall with 1.1 inches maximum 60-minute intensity.

The recurrence interval for the flood runoff ranged between 100 and 200 years for the treated pine watersheds. This corresponds favorably with the recurrence interval of 100 years for 24-hour rainfall of 5.5 to 6.0 inches (U.S. Department of Commerce 1967).

Sediment.—Annual sediment yields from clearcut Watershed 12 have varied from 0.01 to 27 tons per acre since treatment. On stripcut Watershed 9, with a residual basal area of 81 ft^2/acre, they have varied from 0.01 to 1.3 tons per acre. On heavily thinned Watershed 17, with 30 ft^2 basal area, they have been from 0.03 to 0.32 ton per acre.

Watershed 11 does not have an installation to measure total sediment yield, but suspended sediment samples were collected periodically before and after the grazing treatment was imposed. Average suspended sediment concentra-

[6] *Baker, Malchus B., Jr., Harry E. Brown, and Norman E. Champagne, Jr. Hydrologic performance of the Beaver Creek watersheds during a 100-year storm. Paper presented at Amer. Geophys. Union meeting, San Francisco, Calif., 19 p. Dec. 1971.*

Table 3.--Summary of effects of treatments on flood peaks for the September 1970 storm on the pine watersheds (all discharges rounded to nearest 50 $ft^3/s/mi^2$)

Watershed, by treatment, and year treatment completed		Flood peak			Estimated recurrence interval[1]	Since treatment
		Estimated, untreated conditions	Actual	Estimated difference due to treatment		
		- - - $ft^3/s/mi^2$ - - -			- *Years* -	
Watershed 12-- 100% clearcut	1967	450	1,200	750	150-200	3
Watershed 9-- 32% clearcut in uniform strips	1968	500	600	[2]100	100-150	2
Watershed 11-- 60% utilization of perennial grass	1967	450	850	400	100-150	[3]12,(3)
Watershed 17-- 75% thin	1969	400	750	350	100-150	1
Watershed 14-- 33% pine clearcut in irregular strips, thinning between strips; 50% basal area removed overall	1970	450	550	[2]100	100-150	([4])

[1]Estimated recurrence intervals were determined by the U.S. Geological Survey, Tucson, Arizona, using regionalized peak discharge data from the Beaver Creek watersheds.
[2]Only a marginal response if indeed significant.
[3]Twelve years since clearcut and 3 years since grazing treatment imposed.
[4]Treatment 40 percent completed.

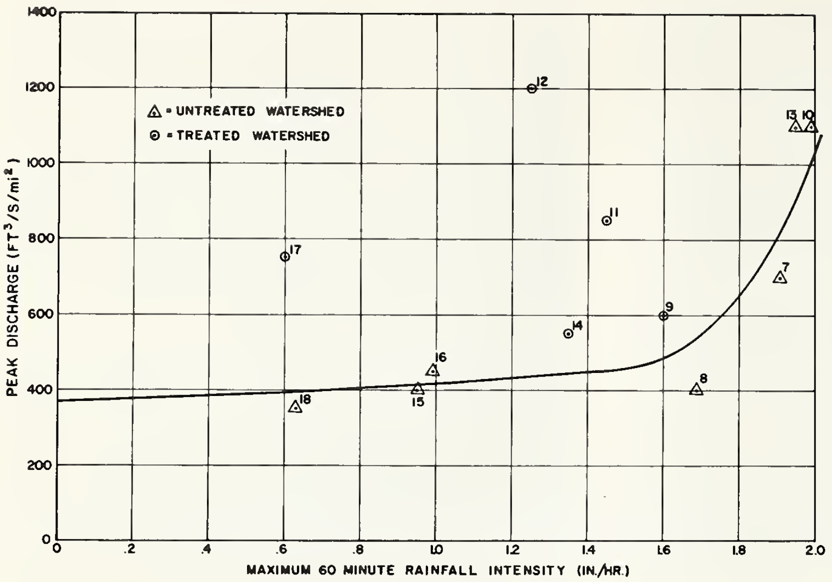

Figure 13.—

Flood peak response determined by relationship of peak discharge to maximum 60-minute rainfall intensity.

tion prior to grazing was 176 p/m (38 samples) and the average following treatment was 113 p/m (29 samples). The difference between these two averages is not significant at the 20 percent level.

The largest sediment yield, 27 tons per acre, was produced on Watershed 12 after it had just been clearcut. Because all slash had been pushed into windrows, nearly 100 percent of the surface soil was disturbed by the piling equipment. The entire treatment was completed in June 1967. On July 31, 1967, this watershed received 2.2 inches of precipitation with a maximum 30-minute intensity of 2.8 inches per hour. The resulting 2.1 inches of runoff overtopped the flume and washed out the sediment basin below it. The sediment yield of 27 tons per acre was estimated from measurements in the field and substantiated by measurements obtained from pre-and poststorm aerial photographs of the watershed.

From the sediment yield records obtained during the past 11 years on Beaver Creek, and from knowledge of the sediment losses resulting from various treatment intensities and storm frequencies, it appears that 27 tons per acre is approaching the maximum sediment loss potential from watersheds with similar characteristics in the ponderosa pine type.

It is difficult to develop a relationship to adequately predict sediment yields because of the limited amount of data. However, an initial attempt will be described in a later section, using maximum annual 30-minute precipitation intensity and timber basal area as independent variables.

Water quality.—TDS (total dissolved solids), which are indicative of overall water quality, were apparently not affected by treatments. Although the mean TDS from treated watersheds was nearly 5 milligrams per liter greater than from untreated watersheds, a difference of nearly 10 percent, analyses were not statistically conclusive.

Analysis of correlation between discharge in the flume at the time of sample collection and TDS in the samples from the pine watersheds yielded a coefficient of -0.44, not significant at the 5 percent level. Thus no clear relation is evident between rate of flow and quality of runoff water.

Samples from both treated and untreated watersheds met water quality standards for drinking water, fish and aquatic life, and unrestricted use for irrigation. Only iron approached an unacceptable level for drinking water. All samples had extremely low sodium absorption ratios. Electrical conductivity values of all pine watershed samples were 72 μ mho/cm or under.

Based on the classification of Durfor and Becker (1964, p. 27), water samples from the pine watersheds were soft (0 to 60 mg/l of $CaCO_3$).

Suspended sediment was determined on samples taken concurrently with those reported here. Correlation analysis showed no consistent relation between suspended sediment and TDS of the waters.

Timber.—No direct measures of timber responses have been possible because the watersheds have not had time to respond to the treat-

ments. Thus the only means available for determining response has been the simulation model described in a later section. This model uses Beaver Creek inventory data consisting of an average stand table for each soil type. Estimates for rate of natural regeneration and mortality are determined for each soil type. Functions are computed for growth and the effect of density on growth.

All of the treatments were simulated for a full rotation, and the total products harvested are estimated in table 4. Past management was also simulated for each watershed, and these results are also included in the table. Past management consisted of harvest cuts every 40 years to remove overmature and dying trees, salvageable snags, and some mature and older blackjacks. No timber stand improvement work was done, and no pulpwood was sold.

Volumes removed in the initial treatment cuts were omitted from the simulation analysis in order to best describe the long-term effects of the treatments without the bias introduced by the initial cut. Consequently the cleared Watersheds, 11 and 12, produce no timber under the alternative treatment prescriptions, and a net loss in timber products is shown. Every 40 years, one-third of Watershed 9 would be cleared, resulting in young stands capable of rapid cubic-foot growth until tree growth diminishes due to increasing stand density. This pattern causes rapid growth on young trees but slow growth in older saw log-sized stands, with a net gain in cubic-foot volume but net loss in board-foot volume. While one-third of Watershed 14 is cut every 40 years, timber production is higher than under past management for two reasons: the cut strips are planted, thus keeping the watershed under full production, and the leave strips are thinned for stand improvement and growth. Estimates for Watershed 17 indicate that it may be possible to maintain good volume production at very low stocking levels by intensive management.

Range.—With the exception of the grazing treatment on Watershed 11, the Beaver Creek treatments consist of reductions of timber

Table 4.--Predicted treatment effects on wood products sold from the pine watersheds for a 120-yr rotation

Watershed, by treatment, and year treatment completed		Volume per acre					
		Under past management[1]		Under alternative-treatment prescriptions[2]		Difference	
		ft^3	*fbm*	*ft*^{3}	*fbm*	*ft*^{3}	*fbm*
Watershed 12-- 100% clearcut	1967	800	4,200	0	0	-800	-4,200
Watershed 9-- 32% clearcut in uniform strips	1968	1,500	7,500	2,000	6,300	500	-1,200
Watershed 11-- 60% utilization of perennial grass	1967	500	2,800	0	0	-500	-2,800
Watershed 17-- 75% thin	1969	1,400	6,800	3,900	11,700	2,500	4,900
Watershed 14-- 33% pine clearcut in irregular strips, thinning between strips; 50% basal area removed overall	1970	1,100	5,500	3,300	11,200	2,200	5,700

[1]Past management consisted of harvest cuts every 40 years to remove overmature and dying trees, salvageable snags, and some mature and older blackjacks.

[2]Volumes removed in the initial cut were omitted in order to best describe the long-term effects of the treatment without the bias introduced by the initial cut.

overstory by differing degrees and in different patterns. Such reductions invariably result in an increase in the production of herbaceous plants, and often of shrubby understory plants as well. These responses increase with increasing degrees of overstory removal.

On Watershed 12, all timber overstory was removed. The native herbaceous and shrubby plants increased an average of 504 pounds per acre for the five posttreatment years (table 5). This increase in understory plant yields means greater livestock and big-game carrying capacities. If the cattle carrying capacities are based on: (1) grass production only, (2) assumption that 750 pounds of allowable forage disappearance represents one animal-unit of carrying capacity, and (3) 40 percent maximum allowable use, then the carrying capacity for cattle would have increased from 0.11 animal-unit month per acre to 0.23 AUM per acre as a result of treatment.

Watershed 9 was stripcut with no thinning of the leave strips, thus herbage response can only be expected on one-third of the area. By the second year after treatment the average increase in production of understory plants was statistically significant, but not yet of sufficient magnitude to have practical importance. The sampling of the stripcut treatment was relatively intense, but limited to specific combinations of slope, aspect, and soils. Thus the results do not represent a watershed mean.

The treatment of Watershed 11 consisted of spring and fall grazing by livestock, with the

Table 5.--Summary of effects of treatments on herbaceous and shrubby plant production for the pine watersheds on Beaver Creek

Watershed, by treatment, and year treatment completed		Plant group	Production, untreated conditions	Difference between actual and predicted production by years following treatment[1]: 1st	2d	3d	4th	5th	Average	Statistical significance of average change[2]
			- - - - *Pounds per acre* - - - -							
Watershed 12-- 100% clearcut	1967	Grasses	200	176	252	174	262	319	237	0.01
		Forbs,half-shrubs	109	313	168	156	211	382	246	.02
		Shrubs	20	-20	1	11	45	66	21	NS[3]
Watershed 9[4]-- 32% clearcut in uniform strips	1968	Grasses	30	12	10	--	--	--	11	.05
		Forbs,half-shrubs	26	49	32	--	--	--	40	.01
		Shrubs	11	3	12	--	--	--	8	NS
Watershed 11-- 60% utilization of perennial grass	1967	Grasses	390	-118	-1	215	303	-12	77	NS
		Forbs,half-shrubs	339	-131	-104	-181	-61	-5	-96	.10
		Shrubs	0	1	2	0	1	0	1	NS
Watershed 17-- 75% thin	1969	Grasses	86	--	--	--	--	--	--	--
		Forbs,half-shrubs	45	--	--	--	--	--	--	--
		Shrubs	15	--	--	--	--	--	--	--
Watershed 14-- 33% pine clearcut in irregular strips, thinning between strips; 50% basal area removed overall	1970	Grasses	137	--	--	--	--	--	--	--
		Forbs,half-shrubs	86	--	--	--	--	--	--	--
		Shrubs	2	--	--	--	--	--	--	--

[1]Predicted production is an estimate of production that would be expected assuming the watershed had not been treated.

[2]Different sample designs and sampling intensities were used on the different watersheds; therefore, the reliabilities of the estimates differ.

[3]In 1968 and 1969, attempts were made to control Gambel oak sprouts with chemicals. The original treatment plus followup chemical application suppressed shrub (browse) production for several years. Since that time, Gambel oak sprout production has been steadily increasing. Additional sampling has indicated that oak sprout production has increased three to five times since treatment.

[4]Sampling was limited to sites exceeding 10 percent slope. These sites have greater timber densities and therefore low initial herbage production.

intent of removing one-half of the standing crop of perennial grasses during each grazing period. The proportion of the total perennial grass production removed yearly was 60 percent for the first 4 years of treatment, but dropped considerably the fifth year. This treatment caused no significant change in the production of grasses, but did apparently reduce the production of forbs. If we again base the carrying capacity for cattle upon the grasses alone, we would conclude that there has been no change in carrying capacity as a result of this treatment.

The understory plant responses on Watersheds 17 (3/4 thin) and 14 (stripcut plus thin) have not been directly sampled. It appears that after several posttreatment years these watersheds are producing about 100 pounds of additional herbage per acre, about one-half being grass. The dry years since treatment have obviously slowed the plant responses. Therefore, additional recovery time is needed before livestock carrying capacity will increase meaningfully.

In evaluating the effect of a treatment on livestock carrying capacity, we must consider whether the animals can or will take advantage of the increased forage yields. In the case of Watershed 12 the topography is relatively gentle, abundant water is nearby, and the cattle have demonstrated that they will distribute themselves over the watershed. Here we can conclude that the apparent increase in carrying capacity is realistic. On other areas such as Watershed 9, any increase in apparent carrying capacity will have to be tempered by the knowledge that livestock will probably spend little time on the steeper areas.

Wildlife.—The impact of watershed treatments upon wildlife values has been measured in two ways: (1) production of forage plants preferred by deer, and (2) big-game fecal droppings as an indirect index of animal use.

We do not know what a given increase in preferred plants means in terms of big-game carrying capacity, but an increase in the forage supply should be beneficial if cover requirements can still be met (Reynolds 1969). Big-game on Beaver Creek are known to prefer areas with better-than-average forage supplies (Clary and Larson 1971). The overstory reduction treatments applied to Watersheds 12 and 9 resulted in increased production of the preferred deer forage plants (table 6). The livestock grazing treatment on Watershed 11, on the other hand, reduced preferred plants.

The response of deer and elk to the treatments, as indexed by fecal droppings, roughly parallels the production of preferred forage plants. On Watershed 12 with the highest increase in preferred plants, deer use increased noticeably (table 7). Big-game use changed little on Watershed 9, which showed only a small increase in preferred plants. On Watershed 11 where production of preferred plants has been severely depressed, deer use remains low, while elk use has plummeted. On the other hand both deer and elk appear to be responding to the treatment of Watershed 17, even though there does not appear to be a large increase in herbage yields.

In general, opening the ponderosa pine canopy to enhance the understory forage supply improves deer and elk habitat (Neff 1972). It is still not possible, however, to predict the exact game response to any particular treatment.

The question of quantifying wildlife cover is a difficult one. Most wildlife biologists and wildlife managers avoid attempting to quantify cover requirements. Clearcutting Watershed 12 (455 acres) was expected by some to create a wasteland, from a deer standpoint. In fact, however, deer use of this watershed is several times higher than before treatment. The deer are apparently attracted by the abundant forage supply, while the slash windrows and Gambel oak sprouts provide sufficient cover. A critical evaluation of the effect of these treatments on wildlife cover requires additional understanding of the specific requirements of individual species.

Preliminary predictive models based on pellet counts were developed from several different studies. The graphs (fig. 14) are presented as an initial basis for evaluating the impact of a given treatment on deer use. The three different situations illustrated describe the relation of deer use to basal area.

The shape of relationship A applies to cleared forest openings smaller than 40 acres where the lack of cover does not inhibit deer use (Reynolds 1969). On these small areas, average big-game use will likely be proportional to forage supply (Reynolds 1962; Patton 1969) — highest at low timber basal areas.

Relationship B applies to areas 40 to 500 acres in size, surrounded by forest. Under these circumstances deer use peaked on a heavily thinned watershed of 300 acres where there was a moderate increase in forage and some remaining tree and slash cover (Neff 1973). The shape of relationship C is applicable to broad, uniformly forested areas (Reynolds 1969) where both cover and forage are provided on the same site.

Future intensive land management will undoubtedly be based on diversified sites, habitat types, and land response units, resulting in a mosaic of treatment patterns. Under these cir-

Table 6.--Summary of effects of treatments on forage plants preferred by deer in the pine type on Beaver Creek

Watershed, by treatment, and year treatment completed		Deer forage production, untreated conditions	Difference between actual and predicted production by years following treatment[1]						Statistical significance of average change[2]
			1st	2d	3d	4th	5th	Average	
		- - - - - *Pounds per acre* - - - - -							
Watershed 12-- 100% clearcut	1967	69	233	75	47	86	166	121	0.05
Watershed 9-- 32% clearcut in uniform strips	1968	16	21	13	--	--	--	17	.01
Watershed 11-- 60% utilization of perennial grass	1967	190	-166	-63	-87	-80	-46	-88	.10
Watershed 17-- 75% thin	1969	30	--	--	--	--	--	--	--
Watershed 14-- 33% pine clearcut in irregular strips, thinning between strips; 50% basal area removed overall	1970	37	--	--	--	--	--	--	--

[1]Predicted production is an estimate of production that would be expected, assuming the watershed had not been treated.
[2]Different sample designs and sampling intensities were used on the different watersheds; therefore, the reliability of the estimates differ.

cumstances, areas of uniform treatment will be limited to several hundred acres in size, thus making relationship B most applicable.

Esthetics.—To evaluate esthetic response of the Beaver Creek treatments we have utilized existing criteria from Agriculture Handbook 434 (U.S. Forest Service 1973) as well as current studies by Boster and Daniel (1972).

As indicated in a previous section, the "enclosed," "detail," and "ephemeral" segments of the landscape are particularly susceptible to change by forest treatments. These changes may be in terms of "variety," "deviations," or "contrast," and will result in changed forms, colors, or textures of the landscape.

Consider first the effects of the several land treatments on "variety." From the standpoint of landscape quality, some variety is desirable, but it is less obvious just how much variety is enough.

There is a point at which variety, increasing from zero, becomes visually pleasant or acceptable. As variety continues to increase, it approaches the point where it is no longer pleasant (it may decrease to zero again). In the sketches from the Agriculture Handbook (fig. 15), A and G tend to be the least interesting. The intermediate stages might prove to be the most enjoyable. Although not everyone would rate each sketch the same, most would pick the sketches in the middle range as most interesting and C or E, where the proportions are not equal, are likely to be preferred. Although a precise proportion cannot be determined, we can approximate the range on the variety scale at which visual acceptability is reached.

Figure 15 provides a basis for evaluating changes in variety brought about by several of the Beaver Creek treatments. We might infer that neither the untreated nor the clearcut areas provide desirable variety. The strip shelterwood cut on Watershed 14 would have the highest rank of the treatments. The severe thinning and severe shelterwood treatments on Watersheds 17 and 16 would have intermediate vari-

Table 7.--Summary of effects of treatments on deer and elk pellet group densities in the pine type on Beaver Creek[1]

Watershed, by treatment, and year treatment completed		Pellet group density, untreated conditions		Difference between actual and predicted pellet group densities by years following treatment[2]						Evaluation[3]
				1st	2d	3d	4th	5th	Average	
				Pellet group per acre per month						
Watershed 12-- 100% clearcut	1967	Deer	0.4	1.2	1.3	1.6	0	1.6	1.1	Meaningful
		Elk	1.0	-.6	-.6	-.2	([4])	.2	-.2	Not meaningful
Watershed 9-- 32% clearcut in uniform strips	1968	Deer	.5	-.1	.9	.2	-.1	--	.2	Not meaningful
		Elk	1.2	-1.0	-.6	-.8	1.2	--	-.3	Not meaningful
Watershed 11-- 60% utilization of perennial grass	1967	Deer	1.2	-.6	-.6	-1.0	-.8	-1.1	-.8	Not meaningful
		Elk	11.8	-8.6	-10.4	-8.7	-10.6	-10.8	-9.8	Meaningful
Watershed 17-- 75% thin	1969	Deer	.8	.2	3.6	1.9	--	--	1.9	Meaningful
		Elk	1.0	.3	6.3	4.3	--	--	3.6	Meaningful
Watershed 14-- 33% pine clearcut in irregular strips, thinning between strips; 50% basal area removed overall	1970	Deer	.6	1.5	--	--	--	--	1.5	?
		Elk	.4	.6	--	--	--	--	.6	?

[1]Adapted from: Neff, Don J. Effect of watershed treatment on deer and elk use. Job Progr. Rep. Proj. W78-16, Work Plan 4, Job 5. 1973.
[2]Predicted production is an estimate of production that would be expected assuming the watershed had not been treated.
[3]Evaluation of the treatment effect based on the judgment of the Arizona Game and Fish Department Biologist.
[4]Trace.

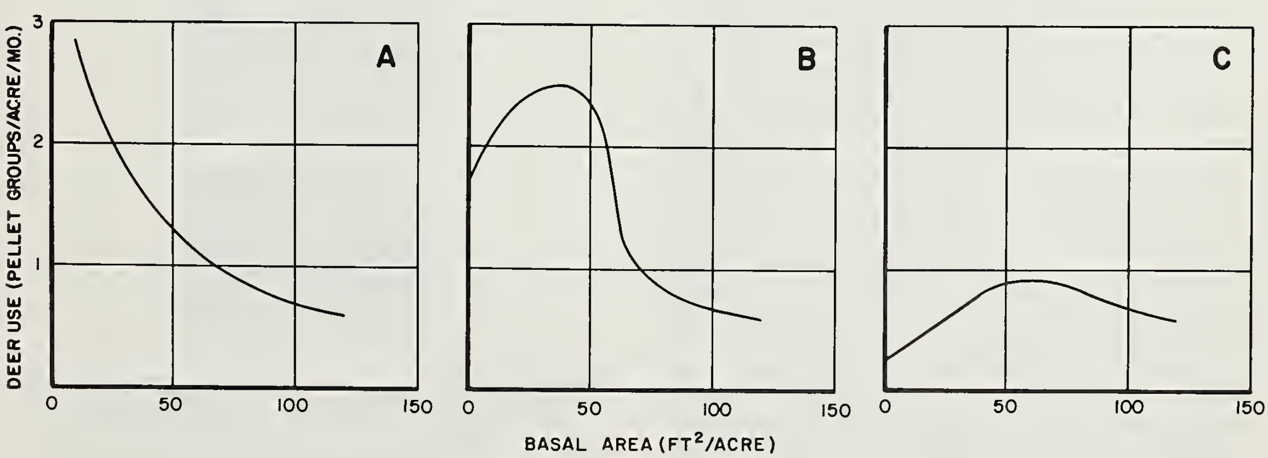

Figure 14.—Relationships of deer use to timber basal area: **A,** Areas of < 40 acres surrounded by forest cover of ⩾ 100 ft.²/acre of basal area; **B,** Areas of 40 to 500 acres surrounded by forest cover of ⩾ 100 ft.²/acre of basal area; **C,** Areas of uniform timber basal area.

ety rankings. If we related the sketches to basal area, it would appear that the intermediate basal area, 50 to 80 ft^2/acre, would have the highest variety ranking, especially if the residual stand is arranged in groups of trees.

The Handbook suggests that the intermediate sketches in fig. 16, (C and D) provide the more desirable degrees of variety. There are definite analogies in the uniform stripcut treatment on Watershed 9 (Sketch A) and the irregular shelterwood stripcut on Watershed 14 (Sketch D). The Watershed 14 treatment scores well in variety except where the strips appear too repetitive. The uniform stripcut on Watershed 9 is much less desirable.

Treatments that create unnatural-appearing deviations from the surrounding landscape are a distinct esthetic detraction. Watershed 12, which was clearcut, is in this category since it is essentially a single large opening covered with parallel windrows of slash. An irregular pattern of forest openings which borrow form, line, color and texture from the surrounding landscape would be preferable.

The ephemeral quality of the landscape can be enhanced by increasing the proportion of Gambel oaks and aspen in forest stands. Gambel oak has been retained on Watersheds 14, 17, and 16 primarily for its wildlife values, with the added result that fall colors are substantially enhanced.

Esthetics are being measured on ponderosa pine areas of the Coconino National Forest and elsewhere by means of an extension of the TSD (theory of signal detection) to evaluate viewer preference for alternative land treatments. The TSD model appears to have considerable promise for this type of evaluation (Boster and Daniel 1972; Boster 1973; Daniel et al. 1973).

TSD methodology was designed principally to distinguish between the two components of perceptual judgment: actual perception and the observers' standards. As noted in Daniel et al. (1973), it was further developed in response to a need to measure image quality when complex photographic displays are subjected to information retrieval or enhancement processes. The Forest Service is attempting to use TSD to answer two questions related to forest management: (1) can observers discriminate reliably among various vegetative treatments, and (2) do observers make differential esthetic responses to the various treatments? Ultimately the TSD approach permits the quantification of the esthetic judgments on a cardinal (or interval) scale rather than on merely an ordinal (ranking) scale.

During its developmental stage this evaluation technique was tested extensively with selected experimental watershed treatments.

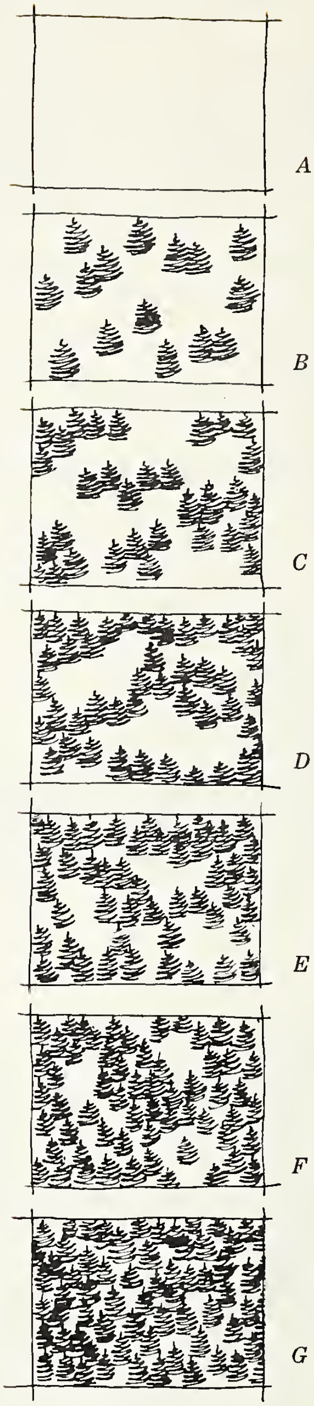

Figure 15.—Degrees of variety in a forest landscape (from U.S. Forest Service 1973).

After sufficient validity and reliability testing, a different set of areas was selected representing a wide array of feasible management options. Numerous definable groups of both forest

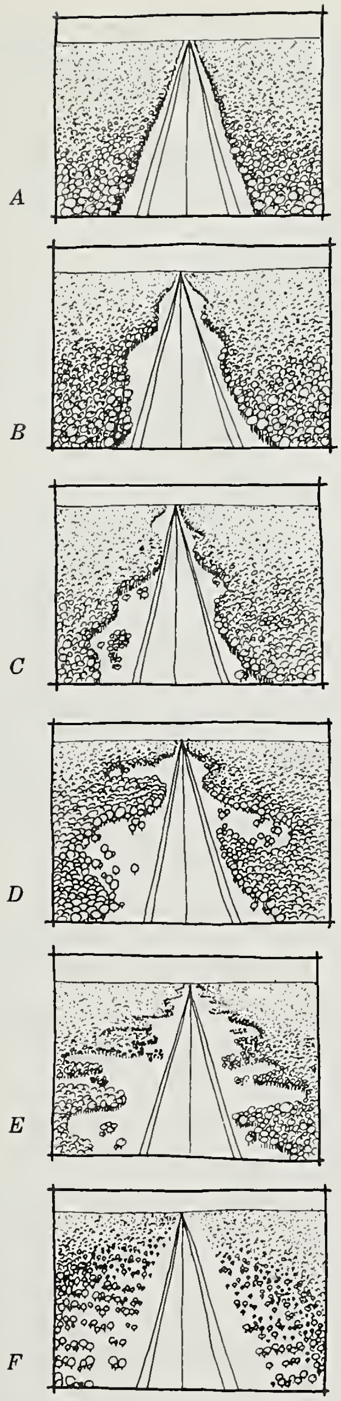

Figure 16.—Degrees of variety in the forest landscape along a road or other cut strip (from U.S. Forest Service 1973).

users and nonusers are now being questioned about their preferences for these alternative management practices:

Management practice	Area Description
Uncut[7]	Woods Canyon Decision Area
Irregular stripcut	Watershed 14
Heavy thin	Watershed 17, 30 ft^2/acre basal area
Moderate thin	Wild Bill Pasture, 60 ft^2/acre basal area
Recent management	'69 NFS "Horse Lake" sale area
Intensive management	'72 NFS "Fred Hought Ridge" sale area (a silvicultural prescription)

One of the most critical esthetic considerations concerns how cutting changes scenic quality. There is general agreement that scenic quality drops markedly immediately following harvest, then increases as vegetation recovers and logging scars heal. The main question is, How much recovery can we expect? Related questions concern whether the pretreatment scenic quality (A, fig. 17) will be reached or exceeded (curves a′ and a, fig. 17) and how much time will be required (x years in fig. 17). Answers to these questions are being sought by Boster and Daniel for several recently treated areas. The "recovery" of Watersheds 9, 14, and 17, plus that of a recently logged area that was lightly cut (Milk Ranch Point), have been followed for several years. These answers can be expected to go a long way toward filling an important void in forest management, providing scientific justification for various management options as they relate to scenic quality.

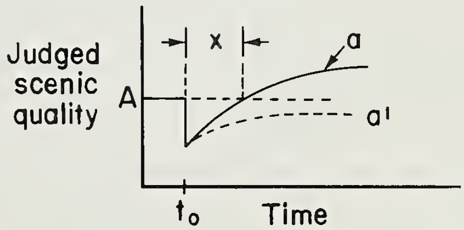

Figure 17.—Esthetic recovery of an area harvested in year t_0. See text for explanation of symbols.

Boster and Daniel have conducted an extensive analysis to identify those factors which consistently increase or decrease viewer satisfaction. This analysis has resulted in a rather

[7] *The "uncut" area that, although lightly cutover, could lend itself to any of the five subsequent management practices.*

small list of significant factors. It has also fostered development of a management tool that will enable landscape architects and others to predict scenic quality solely from viewer judgments of landscape features. The factors used must be periodically updated because people's tastes and preferences change over time.

Landscape architects in Region 3 are being asked to scale representative slides with those factors found to best predict judged scenic quality. Based on their scaling, simple regression equations will be derived with scenic quality as the dependent variable and a small number of identifiable landscape features as the dependent variables. These equations will be usable by the landscape architects. The next step will be to predict judgments of scenic quality from preharvest prescriptions and sketches of proposed treatments (or from photos of existing stands typical of the proposed harvest prescription).

The relation between most of the factors that affect a viewer's satisfaction and the scenic value estimator statistic shows good agreement with theory. For example, variety and diversity (as represented by "tree density" and "average tree diameter") were found to be important factors. Also, scenes lacking harmony with the characteristic landscape (those having large amounts of down wood or slash, for example) have low preference ratings. Very open or very dense forest stands likewise were less preferred than stands with intermediate basal area levels. Figure 21 (page 30) illustrates this latter relationship, with esthetic preference plotted as a function of timber basal area. These and other preliminary relationships are being quantified for use in a model that will predict esthetic preference on the basis of a wide variety of pertinent variables.

Treatment Costs

Since treatment costs are covered in detail in another paper (Turner and Larson 1974), only a brief summary of costs will be presented here. Turner and Larson have developed regression models which predict thinning and piling costs as a function of the degree of timber basal area removed. Thinning costs are related to basal area removed noncommercially, while piling costs are related to total basal area removals including commercial logging. The costs are predicted in terms of dollars, and of man and equipment hour requirements per acre, so that wages and rates can be updated for any situation.

Sensitivity analyses indicate that these piling costs are representative for all but the most extreme conditions of slope steepness likely to be encountered in the Southwest. If the thinning operation involves removal of trees larger than 8 inches in diameter, cost variability may be greater than that accounted for by the thinning model.

By basing estimates on thinning and piling operations, which account for about 90 percent of the total costs, we can eliminate variation due to miscellaneous lesser jobs such as travel which varies between watersheds.

A general model applicable to both experimental and forest operations was obtained by relating costs to basal area removed. The cost to remove noncommercial trees was \$0.79 per ft^2 of basal area, while the piling cost was \$0.28 for each ft^2 of commercial and noncommercial basal area removed.

These costs are based on initial treatments. Estimates of total costs require projections to include subsequent precommercial thinnings and harvests throughout a complete rotation. Because treatments with high initial costs may have lower costs at future cuts, evaluation of a treatment alternative on the basis of initial costs could be very misleading unless future product flows and costs are accounted for and discounted back to present. This procedure can be handled internally by a multiple use allocation model which considers costs and yields at appropriate intervals throughout the planning horizon (Turner 1974).

Preliminary Models for Predicting Resource Responses in the Ponderosa Pine Type

A long-range aim of the Forest Service research program in Arizona is to provide an array of analytical procedures (models) for predicting the following responses to management activities:

1. Terrestrial/biotic responses (timber, range, and wildlife).
2. Hydrologic responses (water yield, quality, and timing, erosion, and sedimentation).
3. Stream and lake/biotic responses (fish habitat and production).
4. Natural beauty and recreation responses (esthetic value and recreation potential).
5. Fire responses (fire size and rate of spread).

Response data from such models will provide input to allocation and scheduling models, which can be used to allocate uses and activities to areas of land in a planning unit and to schedule activities on all planning units in a forest or region.

Physical models are already available for predicting some of these responses on ponderosa pine forest lands. A continuing effort

will be made to determine the suitability of these models and to utilize them to the extent possible in building an overall system of mutually compatible models suitable for use in planning and managing forest and related lands in the Southwest. This overall system of models will eventually be expected to produce all of the response information listed above.

Of the existing water yield models available, the Stanford Watershed Model (Crawford and Linsley 1966) is not suited for application on small watersheds. Because the USDA model (Holtan and Lopez 1971) is not capable of accounting for snowmelt, it is not applicable to areas such as the ponderosa pine type where a majority of runoff is derived from a melting snowpack. Water Yield I (U.S. Forest Service 1972) may be applicable to the Beaver Creek area but is not yet available for testing. Leaf and Brink's (1973) hydrologic model will be tested once it has been modified to function in areas with shallow or intermittent snowpacks. Testing of the BURP model (U.S. Forest Service 1968) is also being planned. Such testing work has been delayed, however, pending completion of an overall problem analysis concerning the development of models needed to provide management information for the Southwest forest ecosystems.

Meanwhile, preliminary models can be used to provide some initial arrays of response data. Two water yield models have undergone preliminary testing on Beaver Creek: Baker and Kovner's regression model, and Rogers' system theoretic model.

Baker-Kovner Streamflow Regression Model

First attempts at modeling streamflow on Beaver Creek have used a regression approach. A multiple regression to predict annual streamflow was developed from 148 observations from 12 watersheds in the pine type. Variables initially considered included precipitation, insolation, soil, geology, and timber density.

The objective was to formulate a model that was in accord with physical concepts influencing the hydrologic regime on the watersheds. Only parameters which logically influenced the water balance were considered. Relationships between parameters were also analyzed to determine if they were independent, linear, or curvilinear.

The initial model was a linear multiple regression which contained six variables. This equation was cumbersome, and examination showed that not all variables were independent. It also became apparent that the relationship was nonlinear. A following modification of the regression included winter precipitation, potential insolation, and timber density. It too was nonlinear.

Since 93 percent of the runoff on Beaver Creek occurs in the winter, winter precipitation was found to correlate best with annual streamflow. The potential insolation variable being used is a percentage of the potential insolation falling on a surface normal to incoming radiation (Fons et al. 1960). At present this variable has been indexed by using the present normal insolation occurring at 1200 hours on February 23. This particular date was selected because much of the snowmelt on Beaver Creek occurs around this time. The insolation variable may be improved in the future by using average annual or winter insolation values for the various watersheds.

Although the relationships developed with the basic data from the Beaver Creek watersheds between streamflow, winter precipitation, and insolation are linear, the expected relationship between vegetation and streamflow is S-shaped because of known upper and lower limits. Timber density parameters considered were number of trees, basal area, and cubic-foot volume per acre. Of these, basal area and cubic-foot volume appear to be most useful.

There is obviously interaction between precipitation, insolation, and timber density. Two interaction terms used in the regression are between winter precipitation-basal area and between winter precipitation-insolation. The form of the regression which has been developed is:

$$\hat{Y} = -5.72 + 0.83X_1 + 0.42X_2 - 0.24X_2X_1^{0.92} - 0.007X_1^2\left[1 - \exp - (X_3/45)\right]^3$$

$$R^2 = 0.69$$

$\hat{Y}$ = Annual streamflow in inches
X_1 = Winter precipitation in inches
X_2 = Insolation as a decimal fraction
X_3 = Timber basal area in ft^2/acre

The observational data for such a model is limited because there are only 12 watersheds. On Beaver Creek, winter precipitation has ranged from 8 to 28 inches, insolation from 0.66 to 0.74, timber volume from 0 to 2,500 ft^3/acre, and timber basal area from 0 to 125 ft^2/acre. It is difficult to accurately control the estimates of eight coefficients in linear and nonlinear form over the full range of combinations with a small amount of data. Therefore the parameters are not necessarily functionally related to the physical processes which control the water balance.

In figure 18 the model provides graphical estimates of streamflow for three winter precipitation levels and a range of basal area levels. To illustrate use of the curves, we would estimate that streamflow will be increased 0.6 inch if basal area is reduced uniformly from 120 to 60 ft^2/acre in a situation where winter precipitation is 15 inches. The model predicts 4.3 inches of streamflow as an average for watersheds on Beaver Creek with 16 inches of winter precipitation and basal area of 116 ft^2/acre. Actual streamflow from these same watersheds is 5.3 inches. For estimating response to strip or patch cutting, it is probably best to consider the clearcut openings to be zero basal area, and use actual basal area for remaining timber stands.

Since on the average, only 5 years of posttreatment data are available from Beaver Creek, predicted responses should only be used to estimate average response for a limited period following treatment. This average response will decrease with time after treatment, and is estimated to be of no practical importance after 20 years.

Over a 14-year period on three watersheds, the model is predicting about 20 percent below derived streamflow (table 8). When all observations from the 12 pine watersheds are considered 69 percent of the variation in streamflow is accounted for by the regression, with the majority being accounted for by winter precipitation. The regression model generally underestimates yields, but is relatively consistent even in an unusually high runoff year such as 1973.

The model was also tested on data from the East and West Fork ponderosa pine watersheds on Castle Creek in east-central Arizona (table 9). East Fork, which is used as the control, has a timber basal area of 122 ft^2/acre. Its insolation is estimated to be 0.61. West Fork, where timber was commercially harvested by prescription, had pre- and posttreatment timber basal areas of 135 and 63 ft^2/acre, respectively. The insolation on West Fork is estimated to be 0.72 (Rich 1972).

The 16-year average actual streamflow on East Fork is 2.8 inches, compared with a predicted average of 2.7 inches (table 9).

The pretreatment 11-year average actual streamflow on West Fork is 2.2 inches and the predicted mean is 2.9 inches; the posttreatment 5-year average of actual streamflow is 2.0 inches and the predicted mean is 1.9 inches.

The regression model predicted average pretreatment streamflow for West Fork of Castle Creek within 32 percent and posttreatment streamflow within 6 percent. The long-term mean — including pre- and posttreatment periods — was estimated within 21 percent of the actual. The model estimated a streamflow response of about 0.3 inch, whereas the "actual" response determined by averaging individual

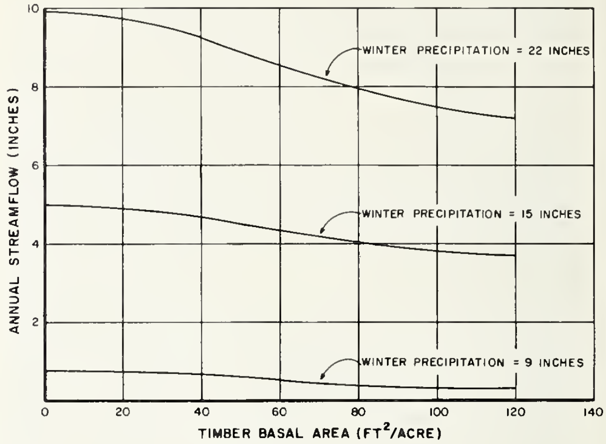

Figure 18.—Predictions of annual streamflow by regression analysis based on winter precipitation, insolation, and timber basal area.

Table 8.--Comparison of observed and predicted streamflow (inches) from three watersheds on Beaver Creek

Water year	Watershed 8		Watershed 13		Watershed 18	
	Observed	Predicted	Observed	Predicted	Observed	Predicted
	Inches					
1960	--	--	3.89	4.90	--	--
1961	2.44	3.26	.94	2.37	--	--
1962	9.23	5.41	4.68	4.50	--	--
1963	.52	1.92	.37	.63	0.30	1.52
1964	2.60	3.92	1.76	1.90	3.09	3.52
1965	13.73	9.09	7.78	6.57	12.34	9.01
1966	10.60	6.58	6.26	4.93	11.95	7.57
1967	3.23	3.71	1.89	1.47	7.46	6.19
1968	8.67	5.73	3.90	4.08	6.03	5.42
1969	11.41	8.07	5.72	4.70	8.45	7.25
1970	3.63	3.42	2.78	1.66	4.88	3.87
1971	1.39	1.44	.37	0	1.03	.80
1972	3.30	2.07	2.15	.36	2.50	.94
1973	16.50	13.78	13.22	11.95	18.51	12.84
Mean	6.71	5.26	4.12	3.57	6.96	5.36
Standard deviation	5.22	3.47	3.52	3.15	5.56	3.73
	Percent difference between means					
	-22		-13		-23	

Table 9.--Comparison of observed and predicted streamflow (inches) from East Fork and West Fork watersheds on Castle Creek in eastern Arizona

Water year	Winter precipitation[1]	West Fork Observed	West Fork Predicted	East Fork Observed	East Fork Predicted
PRETREATMENT		- - - *Inches* - - -			
1956	7.66	0.03	0.00	0.06	0.00
1957	11.18	1.50	1.52	1.73	1.75
1958	19.46	5.87	5.81	7.72	6.28
1959	10.36	.65	1.05	1.56	1.27
1960	17.42	3.40	4.82	4.98	5.24
1961	12.26	.14	2.12	.22	2.39
1962	19.70	4.31	5.92	6.58	6.40
1963	13.43	1.26	2.76	1.86	3.06
1964	9.96	.99	.82	1.44	1.02
1965	13.11	1.60	2.59	2.59	2.88
1966	15.85	4.08	4.03	5.90	4.40
Mean	13.67	2.17	2.86	3.15	3.15
Standard deviation	3.98	1.93	2.03	2.67	2.16
		Percent difference between means			
		+32		0	
POSTTREATMENT		- - - *Inches* - - -			
1967	6.66	.86	.00	.87	.00
1968	18.20	7.73	6.20	8.78	5.64
1969	10.15	.77	1.24	.28	1.14
1970	11.16	.44	1.88	.23	1.74
1971	6.18	.03	.00	.00	.00
Mean	10.47	1.97	1.86	2.03	1.70
Standard deviation	4.83	3.24	2.56	3.78	2.32
		Percent difference between means			
		-6		-16	
LONG-TERM AVERAGE		- - - *Inches* - - -			
		2.10	2.55	2.80	2.70
		Percent difference between means			
		+21		-4	

[1]October 1-April 30

yearly responses was 0.5 inch. The regression estimate for the combined pre- and posttreatment periods on the EastFork of Castle Creek was within 4 percent of the actual.

This limited test indicates that average streamflow can generally be estimated within 20 or 30 percent of the actual in the ponderosa pine type with volcanic soils and climate similar to those on Beaver Creek. Error in streamflow estimates for individual years may be larger, and the model cannot be used on the more permeable sedimentary and alluvial soils without some adjustment.

Rogers' System Theoretic Hydrologic Model

Rogers (1973) has developed a model of the hydrologic behavior of a managed natural ecosystem, following concepts published by Wymore (1967, 1972). The model assumes that an ecosystem may be divided into relatively homogeneous land units and channel reaches. It requires as inputs inventory data describing physiographic and vegetative conditions on each unit and reach, along with information on climate and treatments. It operates on a time interval varying from 5 minutes to 12 hours.

The water and energy balance are computed on each unit of the ecosystem. Water yields are routed from unit to unit and into the channel system. Major processes modeled include those affecting canopy interception, snowpack water and energy balance, mulch layer water balance, surface water balance and overland flow routing, evapotranspiration, soil water balance, interflow routing, and channel routing.

Rogers (1973) includes a computer program for implementing the model, together with instructions for its use. He also gives a procedure for developing the required input data.

The model was independently tested on paired Watersheds 12 and 13. Twelve years of data were available. Watershed 12 had been clearcut after the seventh year while Watershed 13 was a control. The predicted mean (5.27 inches) and standard deviation (4.85) of annual flows for the clearcut watershed was approximately the same as the observed (5.42 and 4.27, respectively, table 10). The predicted mean (1.96) and standard deviation (1.91) for the untreated watershed were significantly less than the observed, however (3.10 and 3.08, respectively).

Comparisons of actual and predicted hydrographs (fig. 19) indicate that, in general, the predicted daily flows follow the same general pattern as the observed flows. During the 1960, 1961, 1963, 1964, 1965, and 1966 calendar years the model generally predicted the start of snowmelt period and time of peak flows to within several days. However, the volumes of peak flows were generally outside the error limits. In 1959 the December melt period was not predicted, and in 1962 the early melt period was missed although later ones were predicted. In 1969 the time of major peaks was predicted although the smaller ones were missed, and in 1971 most of the later peaks were predicted although the first one was missed. For the 150- to

Table 10.--Comparison of observed and predicted streamflow (inches) from two watersheds on Beaver Creek (Rogers' system theoretic hydrologic model)

Calendar year	Watershed 12		Watershed 13	
	Actual	Predicted	Actual	Predicted
	- - - *Inches* - - -			
1959	1.40	0.39	0.73	0.20
1960	4.18	9.91	3.16	3.90
1961	1.83	1.09	.95	.54
1962	7.56	5.36	4.68	2.15
1963	.75	.37	.37	.18
1964	3.15	2.53	1.75	1.17
1965	14.64	16.41	11.62	6.80
1966	5.83	6.26	3.19	1.90
1967	2.95	.51	1.10	.26
1968	10.22	7.17	3.90	1.97
1969	10.63	8.71	5.72	2.60
1970	5.78	8.46	2.78	3.40
1971	1.51	1.38	.37	.44
Mean	5.42	5.27	3.10	1.96
Standard deviation	4.27	4.85	3.08	1.91
	Percent difference between means			
	-3		-36	

200-year Labor Day Storm of 1970,[8] the model overestimated the actual flows.

It is difficult to evaluate the model's performance with these limited test results.

Primary sources of error appeared to be in the climatic inputs, some of which had to be estimated, and in modeling the various effects of treatments on soil and vegetation conditions. More comprehensive testing is needed.

Timber Yield Simulation Model

The first attempt at timber yield modeling on Beaver Creek was a regression model developed from the pine watershed data. The eight independent variables tested included annual precipitation, insolation, soil depth, cubic-foot volume, winter precipitation, elevation, percent cinders, and trees per acre. An equation using the first four independent variables for estimating cubic-foot volume growth accounted for 72 percent of the variation. This predictive ability may be improved by stratifying the watersheds by density and site classes instead of using a

[8]*Baker, Malchus B., Jr., Harry E. Brown, and Norman E. Champagne, Jr. Hydrologic performance of the Beaver Creek watersheds during a 100-year storm. Paper presented at Amer. Geophys. Union meeting, San Francisco, Calif., 19 p. Dec. 1971.*

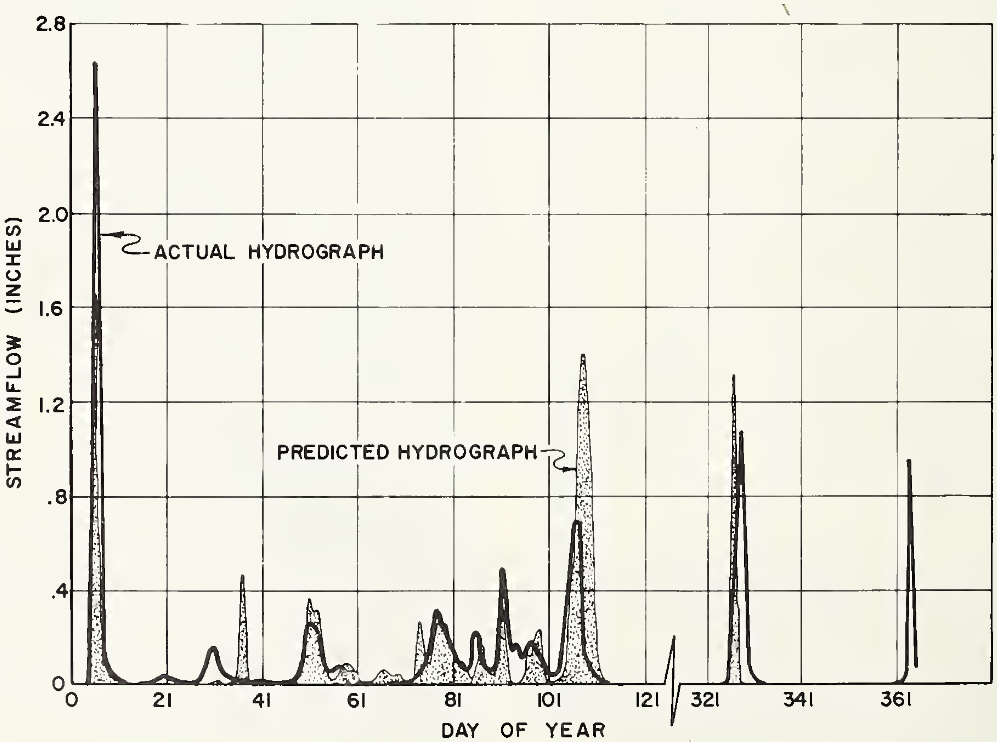

Figure 19.—Test of the Rogers' system theoretic hydrologic model (Watershed 12, 1965).

watershed average. Regression models will never simulate actual stand development, however, because they are unable to accurately duplicate all of the functions representing regeneration, growth, and mortality.

Due to the limitations of regression models, a simulation model is now being developed which employs functions for seed dispersal, germination, seedling survival, tree growth, competition, and mortality.[9] This model is primarily for unevenaged stands, but can be used to estimate future stocking of evenaged stands as well. The model simulates growth of trees through twenty-two 2-inch diameter classes including a zero diameter class for trees less than 1 inch in diameter, and an establishment class for regeneration.

The model is initialized for each stand by reading site index, stand density level (basal area) of residual stand following harvests, time (years) of harvests, type of harvests, and the initial stocking table.

Numerous functions control regeneration in the model. Cone production is a function of stand density and number of trees per acre in cone-producing size classes. Seed production is a function of the number of cones and the number of seeds per cone. Seedling germination and survival depend on total crown cover, seed viability, and expected losses due to rodents, birds, and other factors.

Growth rate is controlled by site index, stand density, and tree size class. A modified stand table projection is used to move a proportion of the trees into the next higher diameter class or classes. The current model uses a 10-year time step for each growth period.

A parabolic mortality function is employed to reflect the higher mortality rate in small and large diameter classes and the relatively low rate in the intermediate classes.

A height-diameter curve is generated for each simulation run. This curve is a function of site index and average growth rate. The generated curve is used in volume calculations which reflect the differences of tree form due to site quality.

Simulation runs have been made to determine projected timber yields for the two dominant soil types on Beaver Creek, over a range of stand density levels (fig. 20). The board-foot volumes projected by the model are consistent with results from other studies (Schubert 1974; Clary et al.[10]) in that yield potential is maximum

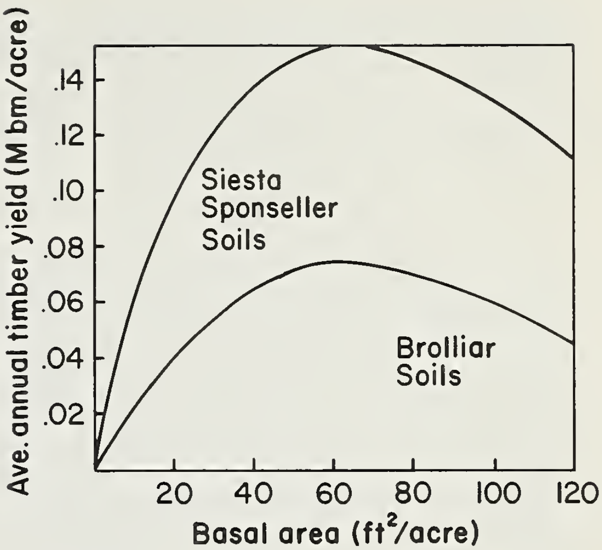

Figure 20.—Sawtimber yield as a function of basal area, for two soil types on Beaver Creek. Larson's model (see text footnote 9) was used to simulate total yield of intensively managed stands over a 140-year period; this amount was then averaged to obtain the estimates of annual yield.

at or near the 60-ft²/acre density level. The projections by Schubert (1974) indicate higher production is possible on better sites, but the general shape of the curve is similar to those generated by this model.

The projections by Schubert (1974) and Clary et al.[10] indicate that annual **cubic-foot** volume growth increases with stand density until the 60-ft² level is reached, and then levels out through the balance of the density levels tested. Larson's cubic-foot volume projections differ from these in that production falls off as basal area increases over 80 ft²/acre. The differences in these projections may be due to initial structure. Schubert's projections are based on evenaged stands carried through maturity. Clary's projections are based on average annual growth rate of pole-sized stands. Beaver Creek stands, on the other hand, are typified by an abundance of saplings and small poles, a shortage of small sawtimber, and an abundance of overmature sawtimber.

A timber yield model developed by Myers (1973) has also been tested. This model, developed for evenaged stands in the Black Hills, uses a regression equation to estimate future diameters of evenaged stands. Since regeneration is not a problem in the Black Hills, the model does not contain functions for cone production, seed production, germination, and survival. Growth rate is simply a function of site,

[9] *Larson, Frederic R. Simulating growth and management of all-aged southwestern ponderosa pine stands. (Ph.D. Diss. to be completed in 1975.)*

[10] *Clary, Warren P., William H. Kruse, and Frederic R. Larson. Cattle grazing and wood production under different ponderosa pine stand densities. Unpubl. ms. Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.*

present diameter, and stand density. Not accounting for regeneration problems, both cubic-foot and board-foot volume projections from Myers' model were about 65 percent greater than those for the same site and initial values projected by Larson's model.

Evaluating Management Alternatives

The previously described models can now be used to provide limited assistance in land use planning. With their help the consequences of alternative management practices can be arrayed in a way that will allow the manager to judge which practices best meet his objectives. Such arrays will eventually be prepared using mathematical programming methods, but meanwhile the procedure can be illustrated graphically with production functions. These functions show how the output of a particular product, such as water, timber, or herbage, responds to increasing degrees of treatments, which in turn are a function of increasing amounts of variable inputs, such as labor, equipment, and materials. General concepts of production functions as they apply to multiple use management were discussed by Lloyd (1969), and some preliminary examples were presented by O'Connell and Brown (1972).

The functions use different levels of timber basal area as the treatment input. Thus to estimate response to a uniform thinning treatment, average pre- and posttreatment basal areas are used to characterize the treatment. For strip or patch cut treatments zero basal area is used for the cleared portion of the management unit, and actual basal area for the remaining portion. This rather gross treatment characterization admittedly imposes certain limitations on the functions — for example they are not sensitive to size, shape, or orientation of forest openings or to juxtaposition of treated areas. Nor do they accommodate treatment features other than forest density reductions, such as planting, seedbed preparation, fencing, salting, and so forth. Nevertheless, forest density manipulations are an important part of most management prescriptions, and even crude applications such as these will provide general management guidelines.

Figure 21 shows preliminary single production functions for sawtimber yield, herbage production, esthetic preference, deer use, streamflow, peak stream discharge, and sediment as functions of timber basal area. These functions have been developed for average conditions on Beaver Creek. They are of varying reliability at this point of development. The best functions are probably those for streamflow and herbage, followed by sediment and peak discharge, all of which were developed by regression analysis. The other curves were handfitted to more limited data. Applicability of the functions elsewhere has not been tested yet except in the case of the streamflow regression (see previous section).

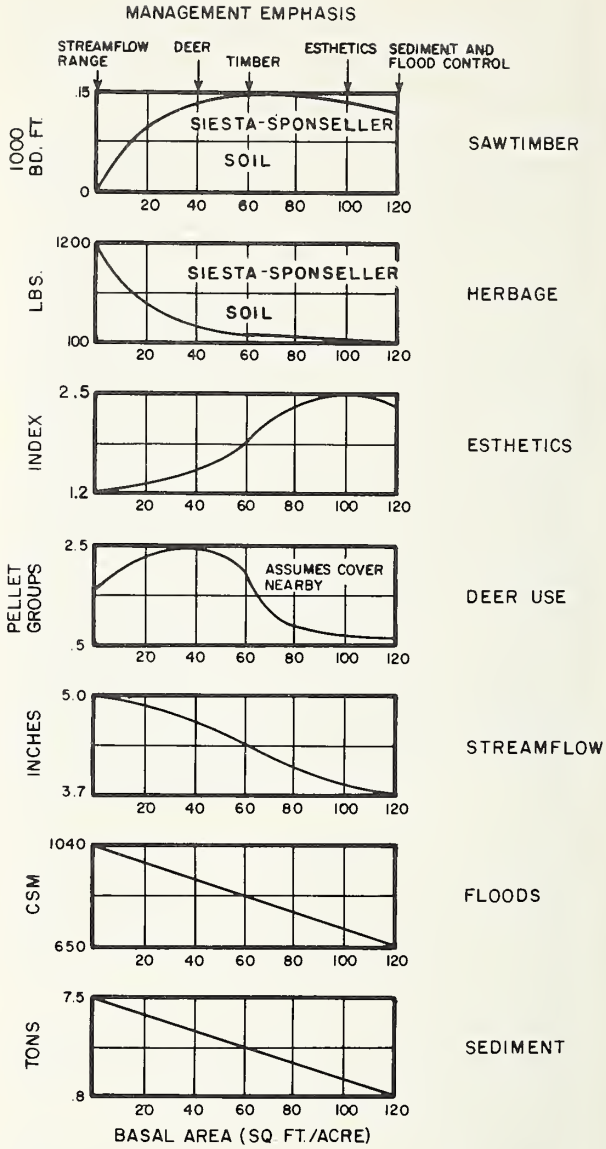

Figure 21.—Example of a multiple use evaluation of alternative management practices (basal area levels) designed to emphasize different uses.

Table 11 shows the above information as percentage changes. From these data one can determine at what basal area level a particular resource or impact is maximized, or stated another way, the level at which to operate to achieve a particular management emphasis. Of course, in this context some management

Table 11.-- Percent changes in products and impacts resulting from basal area reduction

Effect on --	Management emphasis corresponding to basal area reduction from 120 ft^2/acre to:				
	0 (Range and streamflow	40 (Deer use)	60 (Sawtimber)	100 (Esthetics)	120 (Flood and sediment control)
BROLLIAR SOILS:			*Percent*		
Sawtimber *(Mbm/acre/yr)*	-100	44	67	31	0
Herbage *(lbs/acre/yr)*[1]	627	136	82	18	0
Scenic quality index	-152	-168	-183	9	0
Deer use *(pellet groups/acre/mo)*	192	317	150	17	0
Streamflow *(inches/yr)*	35	25	17	4	0
Flood peaks *(ft^3/s/mi^2)*	62	40	30	9	0
Sediment *(tons/acre/yr)*	838	550	412	138	0
SIESTA-SPONSELLER SOILS:					
Sawtimber *(Mbm/acre/yr)*	-100	23	34	18	0
Herbage *(lbs/acre/yr)*	991	182	118	27	0
Scenic quality index	-152	-168	-183	9	0
Deer use *(pellet groups/acre/mo)*	192	317	150	17	0
Streamflow *(inches/yr)*	35	25	17	4	0
Flood peaks *(ft^3/s/mi^2)*	62	40	30	9	0
Sediment *(tons/acre/yr)*	838	550	412	138	0

[1]Herbage relationships similar to those in figure 21 are also available for Brolliar soils.

emphases differ by only 20 ft² of basal area, such as flood and sediment control (120 ft² of basal area) and esthetics (100 ft² of basal area). Such differences cannot be assumed to be statistically significant because of the lack of precision. Within these limitations, however, such functions might still be used to conceptually suggest optimum basal area levels for particular management emphases.

The production functions also provide a basis for estimating differences in products resulting from various levels of basal area. For example, if the basal area is reduced from 120 to 60 ft²/acre on Brolliar soils, streamflow will be increased 0.6 inch, or 17 percent. Sawtimber production resulting from this amount of basal area reduction would increase an estimated 29 fbm/acre/year, or 67 percent. Herbage production would be increased an estimated 90 pounds per acre, or 82 percent.

Physical product-product relationships provide another tool for evaluating management responses. They show graphically how two products or environmental impacts respond to land treatments. If price information is available it is possible to derive economic product-product functions that can be used to determine the most efficient combination of products.

The physical product-product curves are formed by connecting points representing paired outputs at a series of basal area levels. The curves in figures 22 and 23 were prepared from paired outputs from figure 21.

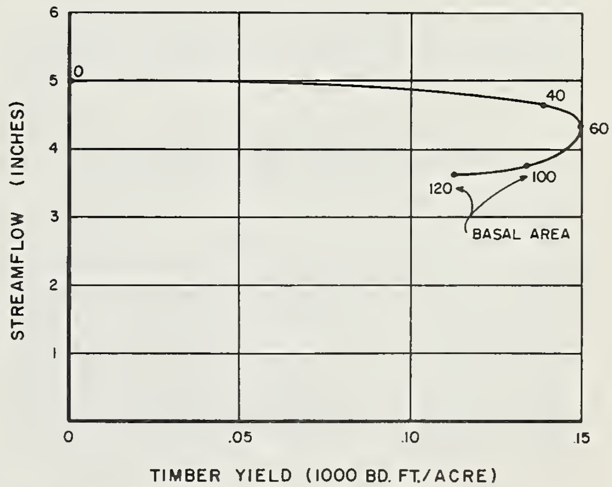

Figure 22.—Product-product function for streamflow-timber. The curve shows relative yields of both products at different basal area levels. As forest density is reduced from 120 to 60 ft², both streamflow and timber yields increase. Below 60, streamflow continues to increase but timber yields decline. One possible interpretation is that basal area should be reduced to 60 because both streamflow and timber yields are increasing to that point.

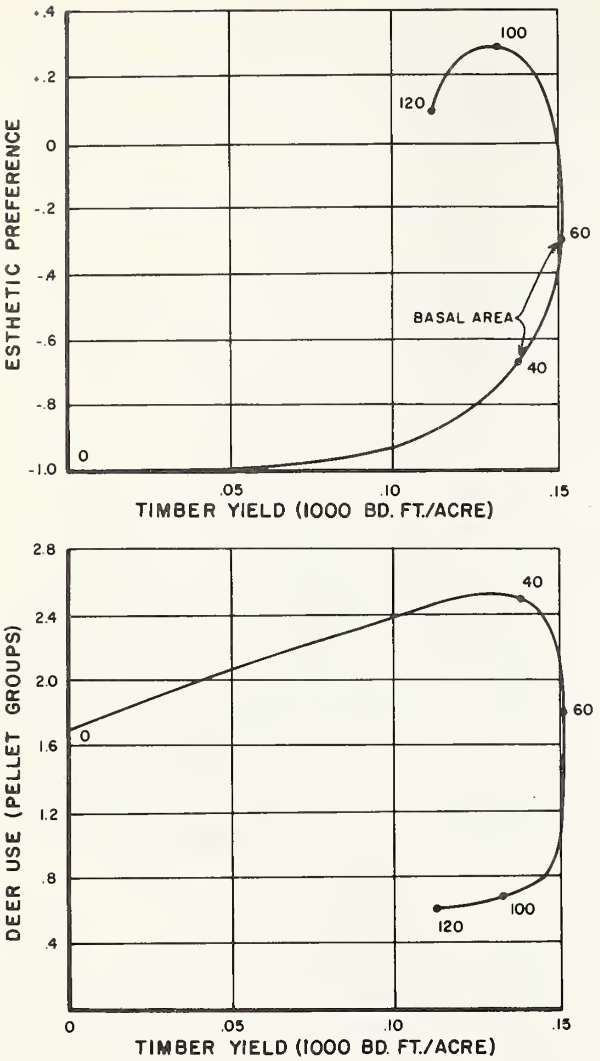

Figure 23.—Product-product functions for esthetics-timber and deer use-timber. Esthetics and timber production both increase as basal area is reduced from 120 to 60. The curve suggests a compatible operating level between 60 and 100. Deer use and timber both increase at basal areas down to 60; this curve suggests a suitable operating level between 70 and 40.

The physical product-product curves can be interpreted by observing the change in the two products as basal area is reduced from a starting level of 120 ft^2/acre. If both products are increasing as basal area is reduced, other things being equal, the manager would be inclined to continue lowering the basal area. This is the complementary phase of the curve. When the point is reached where only one product is increasing and the other is constant or decreasing, there is less incentive to continue reducing basal area. It is in this range that the manager would be likely to establish the treatment level. There is little justification for operating in the third phase where both products are decreasing (illustrated in fig. 22). The captions in figures 22 and 23 state some of these interpretations, the assumptions being that only two products are being considered at a time and that costs are not limiting.

Physical product-product curves for numerous other combinations of products or impacts can be prepared and interpreted similarly; however, not all products or impacts have the same influence on decisionmaking.

Turner (1974) has shown in more detail how the relationship can be used in the development of management prescriptions, considering costs and values of all products and impacts together.

If carried to the extreme there could be different production functions for all important combinations of soil, vegetation, climate, and physiography. Hopefully, however, improved models of ecosystem behavior can be developed that will produce the same information in a more efficient manner.

Meanwhile, the regression models tested so far have quantified a limited number of site factors affecting resource production and environmental impacts. These are summarized as follows:

Products and impacts	Influencing factors				
	Timber density	Soil	Winter precipitation	30-min. precipitation intensity	Insolation
Timber	X	X			
Herbage	X	X			
Esthetics	X				
Deer use	X				
Streamflow	X		X		X
Flood peaks	X			X	
Sediment	X			X	

Needed Research to Provide Better Management Tools

Improved analytical procedures and data are needed for predicting quantity and quality of trade offs among major products, services, and environmental values of ponderosa pine lands in the Southwest. Past research has provided considerable information on the effects of selected management practices under specific conditions on yields of individual market products such as water, timber, and forage. But little information is available on the various

combinations of these products that are attainable from specific management units. Less is available on trade offs between market products and the many nonmarket products and environmental values attainable from a given area.

In this paper some analytical procedures have been presented along with accompanying arrays of multiple use response data. Before these procedures and data can be widely used, however, the capabilities of the various predictive models must be substantially enhanced and their performance tested over a wide range of conditions. Some particularly important needs are:

- Improved performance of hydrologic models to allow better estimates of usable water yield from porous sedimentary and alluvial soil types.
- Improved capabilities for estimating hydrologic responses of various forest cutting patterns and size class distributions.
- Timber yield simulation models that are sensitive to soils, site index, soil water and nutrients, and solar energy. Timber yield models should be capable of responding to a variety of harvesting schemes as well as to disasters such as insect, disease, and mistletoe outbreaks and fire. The models will need to include tested functions for regeneration, growth, and mortality.
- Functions to describe the quantity of fuels for fire hazard prediction.
- Improved capabilities for modeling the response of wildlife habitat and populations to alternative management practices.
- Improved capabilities for estimating nutrients and other factors that affect site productivity.
- Improved capabilities for predicting esthetically pleasing landscapes that will be compatible with land treatment practices designed for other objectives.

A computerized data bank should be developed to accommodate resource characteristics data, climatic data, process or validation data, and predictive output data from alternative modeling systems. Such a data bank should include all available data from the several experimental watersheds in the southwestern ponderosa pine type (Beaver Creek, Castle Creek, Thomas and Willow Creeks, Black River Barometer, and Workman Creek). Also included should be data from the small homogeneous subwatersheds currently being instrumented on Beaver Creek and elsewhere for model testing and validation.

Operational versions of the above models should be developed in conjunction with National Forest Systems, along with an operational data bank and inventory system.

The entire multiple use management planning system should be pilot tested, including inventory, data bank, response models, and economic and management models. Such pilot tests will be necessary to improve the various models and procedures, and to show users as well as the general public how these management planning procedures actually work.

Sensitivity analyses should be performed on the response and management models to determine which variables are most important in the decisionmaking process, and what gaps require additional research. On the basis of these sensitivity tests, research efforts will be reorganized to allow the most efficient and expeditious development of the models into a form widely useful throughout the region.

Conclusions

In summary, four principal resource responses are known to result from manipulating ponderosa pine forests growing on volcanic soils:

- Water yield increases of 1 to 2 inches per year over a 5-year period have been realized as a result of various intensities and patterns of timber reduction. On the more productive pine areas, an average increase of 0.6 inch per year may be realistic, in light of present multiple use consideration and environmental constraints.
- Preliminary results of a timber simulation model suggest that harvestable timber volume growth may be increased even after a considerable reduction of timber basal area.
- Timber overstory reduction results in an increase in understory plant production. Herbage production can increase 500 pounds per acre per year on low to moderately productive soils as the result of complete overstory removal.
- In general, deer and elk habitat are improved by opening up the ponderosa pine canopy to enhance understory forage supply.

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Keywords: Water-yield improvement, forest management, multiple use, *Pinus ponderosa*.

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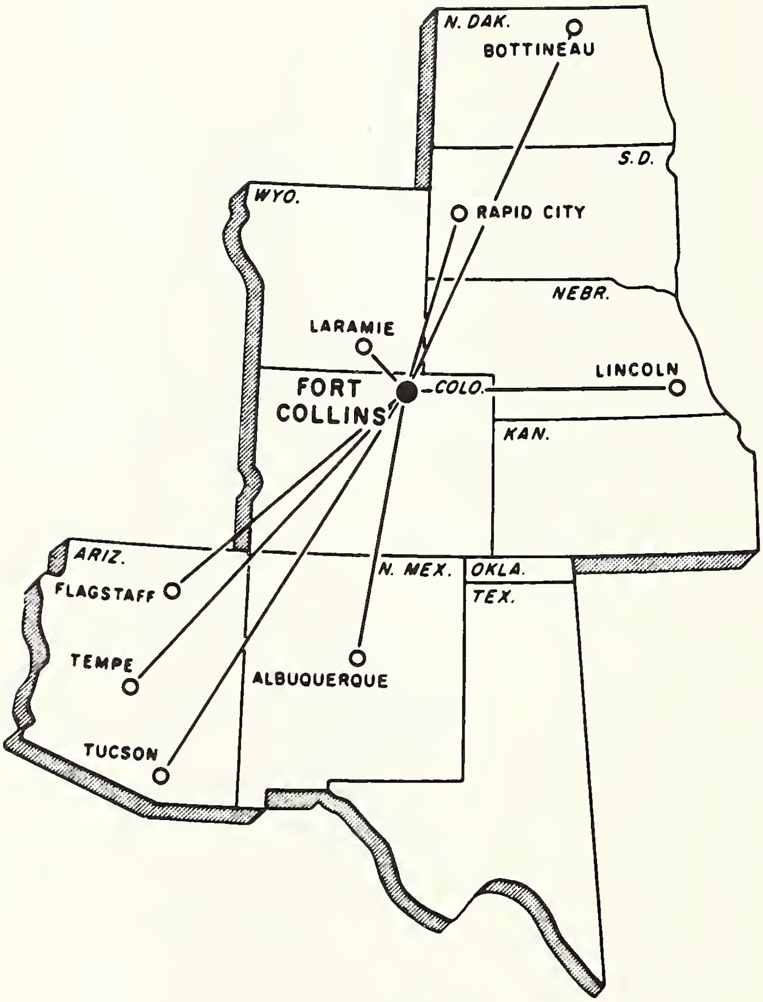

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